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Structure and influence of the Tillamook Uplift on the stratigraphy of the Mist area, Oregon

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AN ABSTRACT OF THE THESIS OF Moinoddin Murtuzamiya Kadri for the Master of Science in Geology presented October 6, 1982.

Title: Structure and influence of the Tillamook uplift on the stratigraphy of the Mist area, Oregon.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

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Gilbert T. Benson, Chairman

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Robert O. Van Atta

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Marvin H. Beeson

Around the hamlet of Mist, in Columbia County, northwestern Oregon, four formations ranging in age from late Eocene to middle Miocene are exposed. The late Eocene Keasey Formation consists of gray, tuffaceous, concretionary mudstone, siltstone and minor sandstone. The unstable and complex environment of deposition is indicated by lutokinesis and wide, shallow submarine channels.

Deltaic deposits of the Pittsburg Bluff Formation

unconformably overlie the Keasey Formation. The lower laminated member (informal) of the Pittsburg Bluff Formation consists of finely laminated mudstone, and interlayered, arkosic sandstone. The upper siltstone member (informal) consists of bioturbated, carbonaceous siltstone and sandstone. It crops out in an arcuate belt generally paralleling the Nehalem River, and thins rapidly towards the west.

The middle Miocene Astoria Formation unconformably overlies the Pittsburg Bluff and Keasey Formations, and consists of poorly consolidated, lithic arkosic to quartzose sandstone and siltstone. Primary structure is well developed in the Astoria Formation; micro cross-bedding and trough cross-bedding are common in the sandstone. The Columbia River Basalt Group is represented by the Grande Ronde and Frenchman Springs geochemical types. Some of the basalt clasts in the conglomerates in the Astoria Formation were derived from Columbia River basalt flows.

Fifty three sedimentary samples were analyzed for their minor and trace element concentrations utilizing instrumental neutron activation analysis. Concentrations of Na, K, La, Sm and Sc, and their ratios appear to establish significant trends. The data suggest a major break from a granitic-metamorphic provenance and a volcanic component dominated provenance between the

Cowlitz and Keasey Formations respectively. The provenance of the Astoria Formation indicates the presence of flood basalts.

Complex faulting along northeast-southwest, and younger northwest-southeast trends primarily involves vertical movements. Exposed faults have steep dips, narrow shear zones, very little drag and form horsts and grabens. Pi-S. diagrams of the Keasey, Pittsburg Bluff and Scappoose Formations indicate near horizontal to northerly or northeasterly dips. Northeast-trending, horizontal Beta axes in the Pittsburg Bluff (siltstone member) and Scappoose Formations parallel the axis of the Tillamook arch. The northwest-trending Beta axis of the Scappoose Formation probably reflects the latest structural grain of the area. Near horizontal dips of the strata, especially those of the post-Cowlitz age, the high angle faults, and the horizontal Beta axes probably preclude uplift involving extensive compression and thrusting. The post-Keasey uplift produced an unconformity and restricted the deposition of coarser lithofacies of the Pittsburg Bluff Formation to the east and around the nose of the plunging axis of the Tillamook arch. Post-Keasey but pre-Astoria uplift along the axis of Tillamook arch and Willapa Hills upwarp produced the east-west trending Columbia River synclinal trough. The Astoria Formation and the Columbia River basalt flows are depositionally confined to this structural downwarp. Continuity in the outcrop pattern of the middle Tertiary units perhaps precludes any large scale strike-slip offset.

STRUCTURE AND INFLUENCE OF THE TILLAMOOK UPLIFT ON THE STRATIGRAPHY OF THE MIST AREA, OREGON

by

MOINODDIN MURTUZAMIYA KADRI

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
in
GEOLOGY

Portland State University

1982

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

The members of the committe approve the thesis of Moinoddin Murtuzamiya Kadri presented October 6, 1982.

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Deepest and most sincere gratitude and appreciation is due Sal and Betty Kadri for their generous support which helped considerably in completing this thesis. Lastly, my parents perseverance, understanding and support is deeply appreciated.

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INTRODUCTION

Location

The thesis area is located in Columbia County, northwestern Oregon, around the hamlet of Mist. The area covers approximately 110 square kilometers, and includes parts of T. 5 and 6 N., R. 4 and 5 W. The location of the area is shown in Figure 1. Oregon Highways 47 and 202 provide the primary access to the area; the interior is accessible by logging-roads.

Purposes of Investigation

The objective of this study were (1) to construct a detailed geologic map of the study area, (2) to develop the pattern of the structure through field observations with emphasis on bedding attitudes, (3) an analysis of structural data utilizing equal-area plots to determine geometry and possibly, the sequence of tectonic events, and (4) determination of lineaments drawn from side looking airborn radar imagery (SLAR), high altitude aerial photographs, infra-red photographs and topographic maps.

Methods of Investigation

Field work was conducted during the months of

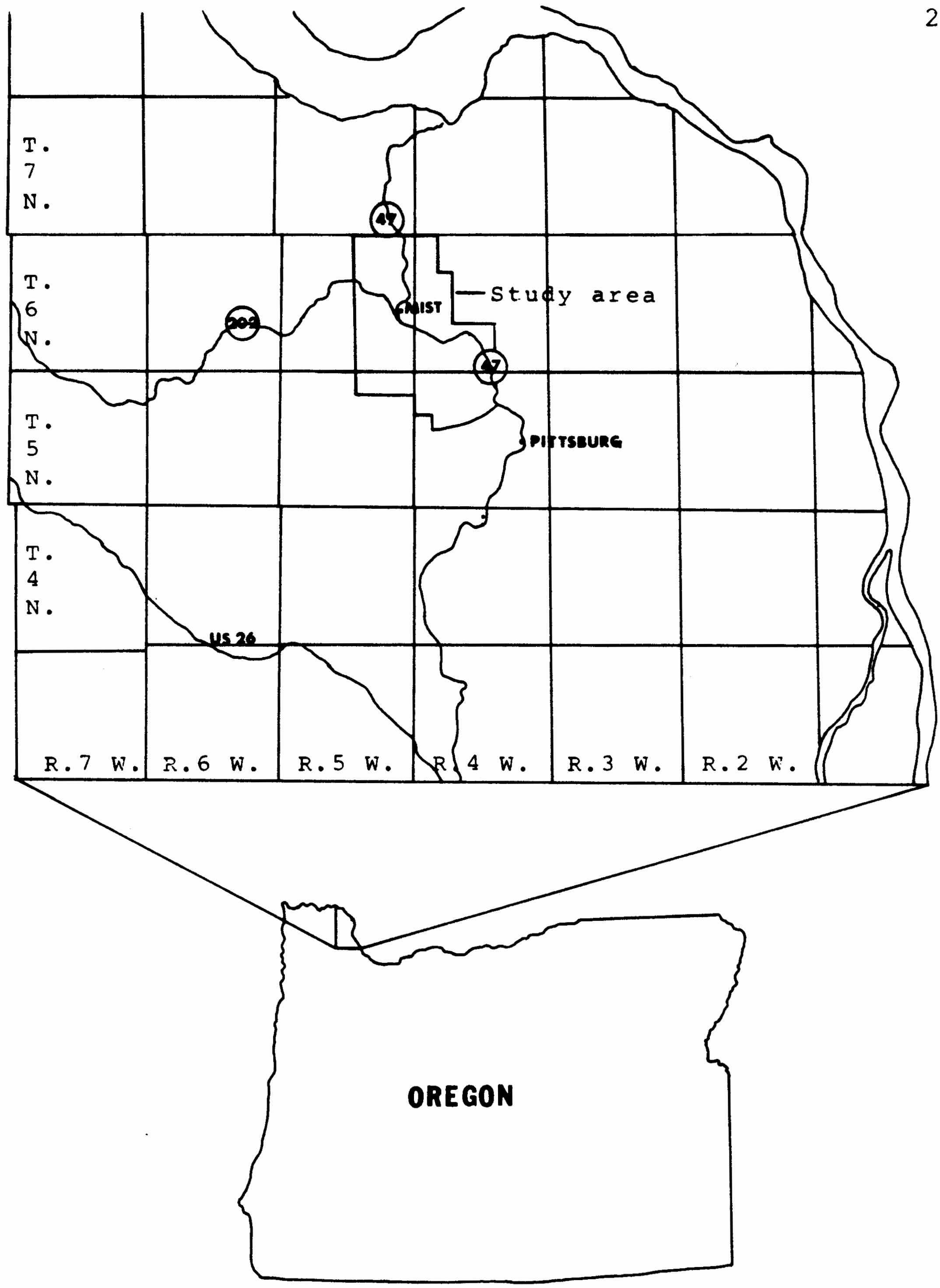


Figure 1. Location map of the Mist area.

August and September, and intermittently through the Fall of 1980. Mapping utilized high altitude aerial photographs at a scale of 1:78,000, and the Cathlamet, Clatskanie, Vernonia, and Birkenfeld U. S. Geological Survey 15 minute quadrangle maps enlarged to a scale of 1:31,250.

Lithology of outcrops, bedding attitudes, and orientation of linear features were noted on the topographic map. Formation contacts were later drawn in part on synthesis of mapped lithology and analysis of cross-sections. A total of 12 samples from the Keasey Formation were analyzed for microfossils. The samples were disaggregated with kerosene and/or quaternary-O, and sieved using a 200 mesh screen.

The analysis of structural data included the construction of pi and beta diagrams utilizing a Honeywell 66/20 computer and programs PIPLOT and BETACAL. The computer-generated pi and beta density plots were hand contoured and reduced to a usable scale. Bedding attitudes from the unpublished geologic map of T. 4,5,6 and 7 N., R. 4 and 5 W., Columbia County, Oregon (Kadri and others, 1980) were incorporated along with the bedding attitudes from the study area in the construction of pi and beta diagrams.

Whole-rock major-element chemical analyses of basalt samples were made by Peter R. Hooper, Washington State

University. Whole-rock and 200 mesh fraction of 53 sedimentary samples and three basalt samples were analyzed by the author (at Portland State University) for minor and trace element concentrations utilizing instrumental neutron activation analysis (INAA).

Limited subsurface data were obtained from the Oregon Department of Geology and Mineral Industries, Diamond Shamrock Corporation, Oregon Natural Gas Development Corporation , Reichhold Energy Corporation, and American Quasar Petroleum Company.

REGIONAL GEOLOGY

Stratigraphic Units

Early to middle Eocene oceanic crust is the basement of the Oregon Coast Range geologic province upon which 7000 meters of volcanic and sedimentary rocks have accumulated (Snavely and others, 1980). Tholeiitic pillow basalts and submarine breccias with minor interbedded tuffaceous siltstone and basaltic sandstone of early to middle Eocene Tillamook Volcanics are the oldest rocks exposed in northwestern Oregon (Snavely and Wagner, 1964).

Overlying the Tillamook Volcanics in the northeastern part of the Oregon Coast Range are: the Cowlitz Formation, the Goble Volcanics, the Keasey, Pittsburg Bluff, Scappoose, and Astoria Formations, and basalts of the Columbia River Basalt Group. In the northwestern part of the Oregon Coast Range, west of the study area, the Oswald West Mudstone, Astoria Formation and middle Miocene basalts overlie the Tillamook Volcanics.

The late Eocene Cowlitz Formation consists of arkosic sandstone, siltstone and mudstone. The Goble Volcanics formed basaltic islands (Van Atta, 1971). In southwestern Washington at Kelso, coal-bearing beds of the Cowlitz Formation are overlain by approximately 300 meters of subaerial lava flows of the Goble Volcanics (Livingston, 1966).

Tuffaceous mudstone, siltstone, and minor volcaniclastic sandstone form the latest Eocene Keasey Formation (Van Atta, 1971; McDougal, 1980). Tuffaceous sediments of the Bastendorf and Alsea Formations in the southern and central Coast Range of Oregon and part of the Lincoln Formation in southwestern Washington are equivalent to the Keasey Formation (Figure 2).

The Oligocene Pittsburg Bluff Formation, which overlies the Keasey Formation, consists of arkosic to lithic arkosic sandstone, siltstone and minor mudstone (Van Atta, 1971). Cross-bedded channels and coal lenses occur in the Pittsburg Bluff Formation (Warren and Norbisrath, 1946). The Tunnel Point and Eugene Formations are correlative to the Pittsburg Bluff Formation in western Oregon.

The Scappoose Formation overlies the Pittsburg Bluff Formation and consists of late Oligocene to early Miocene shallow water tuffaceous sediments (Warren and Norbisrath, 1946). Kelty (1981) indicated the presence of the middle Miocene basalt clasts in the strata previously considered late Oligocene, and therefore, he referred to the lithofacies deposited during middle Miocene as the upper member of the Scappoose Formation. In the study area however, the Scappoose Formation (as defined by Warren and

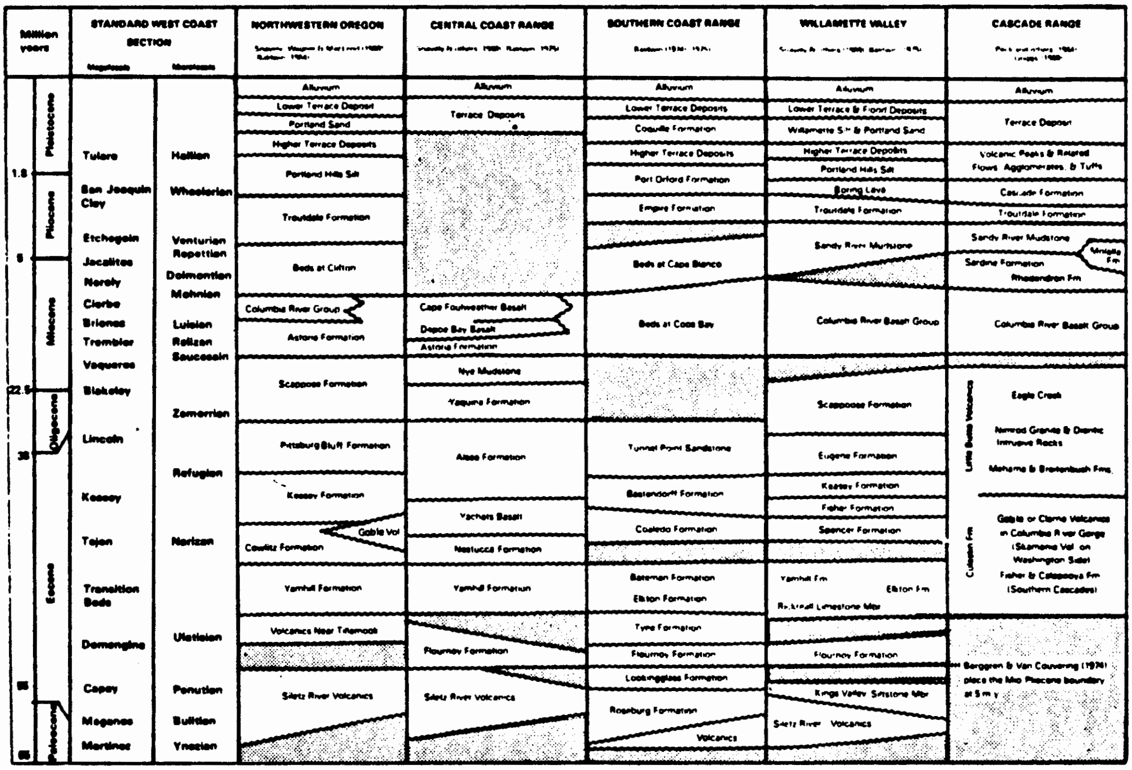


Figure 2. Regional stratigraphic correlation chart (from Baldwin, 1982).

Norbisrath, 1946) is not present. Instead, middle Miocene Astoria Formation overlies the Pittsburg Bluff and Keasey Formations.

Structure

In northwestern Oregon, a northeasterly plunging Tillamook anticlinal upwarp (arch) has produced northerly regional dips and outcrops of progressively younger formations towards the north away from the core of the Tillamook highlands (Wells and Peck, 1961). Progressively younger formations crop out towards the south away from the Willapa Hills upwarp producing a southerly regional dip in the eastern Willapa Hills area in southwestern Washington (Wells, 1981). The Tillamook and Willapa Hills uplifts have produced a broad east-west trending Columbia River synclinal trough (Figure 3).

Upon the north-plunging, northeast-trending arch of the Tillamook "anticlinorium" a series of open, subparallel, northwest-trending folds are superimposed (Newton, 1976). High angle faults are common and they trend either northwest or northeast (Niem and Van Atta, 1973; Bromery and Snavely, 1964). The northwest-trending Portland Hills and Gales Creek faults are among the larger faults so far recognized. Recent drilling activity at Mist has revealed some large east-west trending faults in the subsurface (Bruer, 1980).

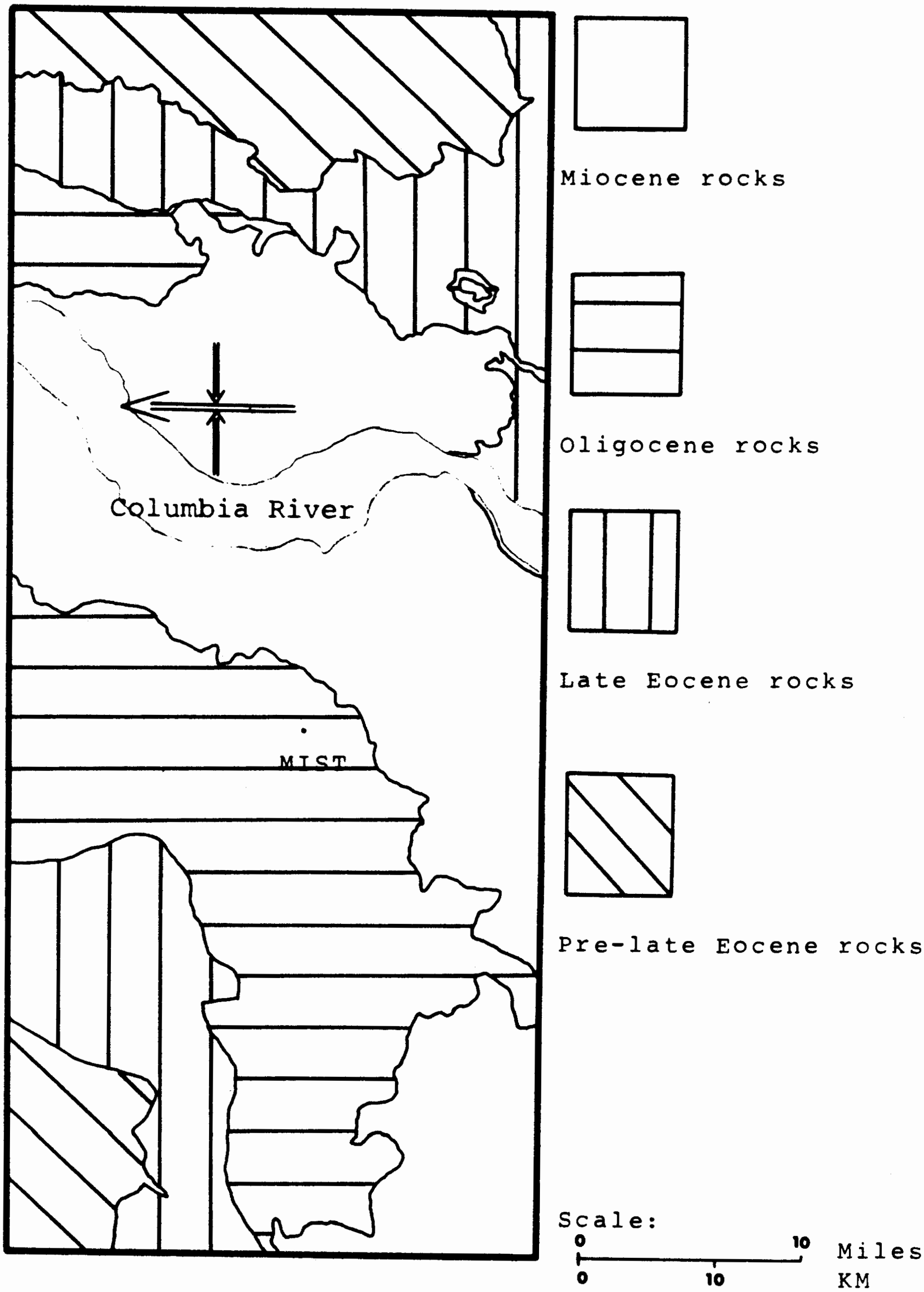


Figure 3. Simplified outcrop pattern of the Tertiary formations of southwestern Washington and northwestern Oregon.

Deformation of the Cenozoic strata of the Oregon Coast Range is produced by intermittent underthrusting, extension, and transcurrent faulting between the North American and Farallon plates (Snavely and others, 1980). The oceanic plate of early to middle Eocene age, the basement of the Coast Range, was accreted to the North American plate when the locus of subduction jumped from its presumed position under or east of the Cascade Range to the present day continental shelf of Oregon (Snavely and others, 1968).

Tertiary rocks of the Coast Range show anomalous direction of magnetization which indicates clockwise tectonic rotation about vertical axes (Simpson and Cox, 1977; Magill and Cox, 1980; Beck and Plumley, 1980). Much of the rotation took place during the Eocene (Simpson and Cox, 1977).

STRATIGRAPHY

The exposed stratigraphic section of the study area consists of four formations ranging in age from late Eocene to middle Miocene. In order of decreasing age, these formations are: the Keasey, Pittsburg Bluff, and Astoria Formations, and the flows of the Columbia River Basalt Group (Figure 4).

Keasey Formation

The oldest Formation exposed in the study area is the Keasey Formation, which consists of predominantly of tuffaceous siltstone and mudstone. The Keasey Formation is underlain by arkosic sediments of the Cowlitz Formation. The high content of expanding clays in the mudstone (Van Atta, 1971), facilitates rapid weathering, and landslides are common.

The dominant lithologies of the Keasey Formation are dark gray, tuffaceous, fossiliferous, concretionary, conchoidally fractured, well indurated mudstone, siltstone and minor volcaniclastic sandstone. The mudstone and siltstone weathers to buff or light brownish yellow, while the volcaniclastic sandstone weathers white.

The Keasey Formation was named by Schenk (1927). Warren and Norbisrath (1946) divide the Keasey Formation

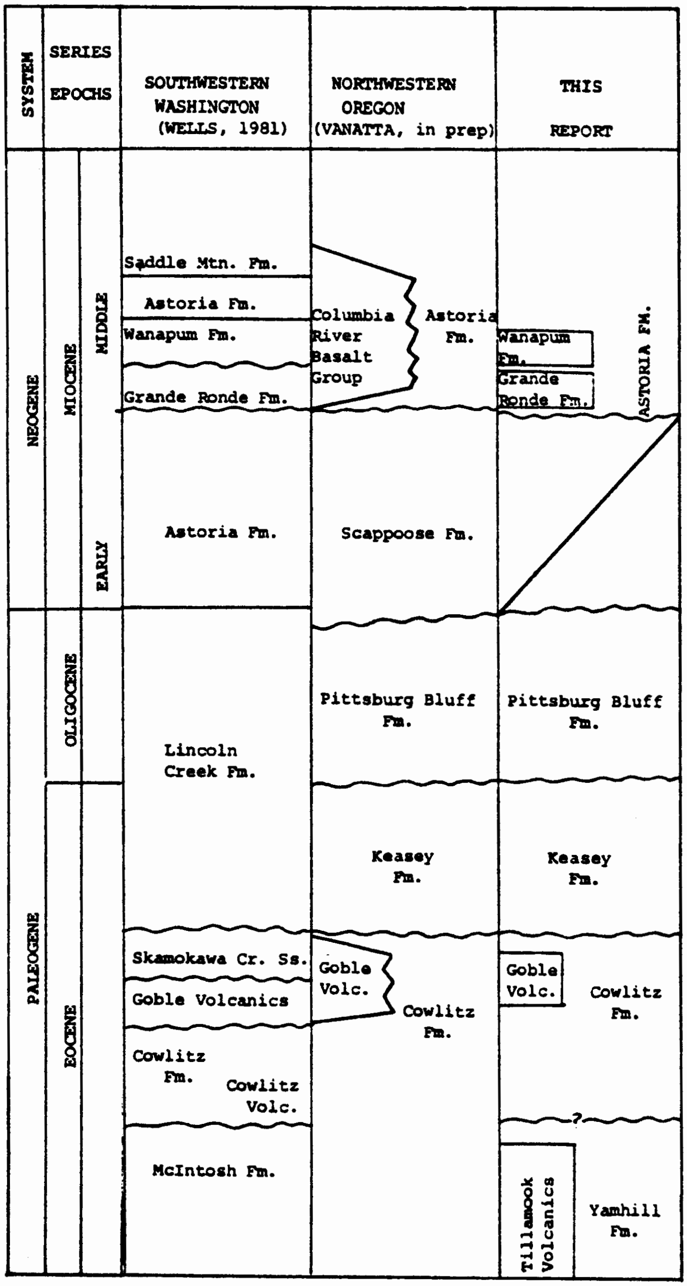


Figure 4. Stratigraphic correlation chart for the study area.

into three members consisting of a lower well-stratified, fossiliferous claystone and siltstone, a middle unstratified tuffaceous siltstone, and an upper faintly stratified, fine grained tuffaceous sandstone and shale. The middle and upper members have a combined thickness of 550 meters in the vicinity of the Sunset Tunnel (Warren and Norbisrath, 1946), approximately 26 kilometers south of the study area. In the study area, only the upper and middle members are exposed. Correlating the rocks of the Keasey Formation from one place to other is difficult. Van Atta (1971) recognized this lack of lateral correlation within the rocks of the Keasey Formation. Petrographically, the Keasey Formation has a higher content of volcanic glass and smectite clay compared to the other formations in the Nehalem River area (Van Atta, 1971).

Primary structures within the rocks of the Keasey Formation are revealed in a few fresh outcrops and locally along the Nehalem River. In the weathered outcrops, the primary structure is completely destroyed. Furthermore, if the fresh outcrop is water soaked, the primary structure is difficult to discern. Within thick-bedded (massive) mudstone and siltstone, the bedding is largely defined by the concretionary layers, alignment of spherical concretions, discontinuous silt lenses, thin volcaniclastic sandstone layers, and alignment parallel to bedding of <u>Helminthoidea</u>, a trace fossil (Figure 5).

Figure 5. Aligned Helminthoidea burrows, and discontinuous silt lenses in the mudstone.

Subtle variations in the lithofacies and bedding characteristics are nowhere more apparent than at the prominent bluff along the Nehalem River (Figure 6) approximately 500 meters south of Mist. The north-northeast trending bluff is one of the best outcrops of the Keasey Formation in the study area. The northern part of the bluff consists of stratified mudstone and siltstone. In the mudstone, Helminthoidea are aligned parallel to bedding. Although carbonized plant material is dispersed in the rock, it is also present as streaks paralleling the bedding. In the middle portion of the bluff, laminated mudstone and siltstone contain thin interbeds of volcaniclastic sandstone. Growth fault (Figure 7) and broad, shallow channels (Figure 8) are apparent in this section. The rocks in the southern portion of the bluff are markedly siltier and highly bioturbated compared to the rest of the exposures along the bluff.

North 20° to 30° east-trending clastic dikes (Figure 9) of varying thickness (averaging 15 cm) consist of coarse volcaniclastic sandstone similar to that of sandstone interbeds. Angular mudstone chunks as big as 15 cm in diameter are incorporated in the dike sediments. The clastic dikes may indicate development of fractures due to shock waves or slumping, and injection of material from the load of overlying sediments or hydrostatic pressure (Reineck and Singh, 1980). Clastic dikes and growth

Figure 6. Prominent bluff south of Mist, along the Nehalem River.

Figure 7. Growth fault in the Keasey Formation; note the truncation of volcaniclastic sandstone layer in the bottom right of the photo.

Figure 8. Wide, shallow submarine channel in the bluff south of Mist, along the Nehalem River.

Figure 9. Northeast-trending clastic dike.

faults indicate an unstable environment of deposition for the Keasey Formation.

A well exposed channel (Figure 8) and other partially exposed wide, shallow channels in the bluff south of Mist lack graded bedding and are filled with laminated mudstone. These submarine channels probably had a fairly low gradient as indicated by lithology and low angle of trough-sets. The low gradient of the channels perhaps reflects the submarine paleotopography which itself probably had a low gradient. Very low gradient of the paleotopography is also indicated by the calcareous concretionary layers (Figure 10). Some of these layers seem to be laterally extensive and have sharp basal contacts and graded bedding with fining upward sequence. These layers are probably the result of rapid deposition. The abundance of volcanic material in the graded beds may imply deposition resulting from volcanic eruptions.

The foraminiferal assemblage of the Keasey Formation indicates Refugian age and deposition in initial bathyal to outer neritic depths (McDougal, 1980). A total of 12 samples were examined for microfossils, but of these, only one contained a diagnostic assemblage of the <u>Uvigerina cocoaensis</u> zone (bluff along the Nehalem River, section 28, T. 6 N., R. 4 W.) indicating a Refugian age and outer neritic to bathyal depth of deposition. Three samples contained radiolaria and diatoms (unidentified).

Figure 10. Oblique view of concretionary layer; note the thinning of the layer to the right of the photo, and two parallel sandstone layers in the bottom-right corner.

Helminthoidea, ichnofossils of the nereites assemblage, indicating bathyal depth, quiet water, and a slow rate of sedimentation (Chamberlain, 1978; Seilacher, 1978), are dispersed throughout the Keasey Formation. However, they are highly concentrated locally, such as along the Nehalem River in the sections 24 and 25, T. 6 N., R. 5 W., and in section 30, T. 6 N., R. 4 W. Moore and Volkes (1953) studied the crinoids of the Keasey Formation and interpreted quiet water sedimentation in moderately deep water adjacent to a shore in an embayment. They also noted the presence of large, fairly well preserved leaves. An euxinic environment is also implied by the presence of pyrite in mudstone. A megafaunal assemblage from the bluff south of Mist indicates a water depth which ranges from less than 15 meters to greater than 800 meters (Zullo and others; in Moore, 1976). Such a large variation in water depth from one outcrop can be explained by the presence of submarine channels. Shells could have been transported in these channels. Hence, paleontological evidence suggests a slow rate of sedimentation in quiet water. The slow rate of sedimentation was probably interrupted by relatively rapid sedimentation in the submarine channels. The observed lutokinesis of the Keasey Formation generally results from rapid sedimentation or overpressure after burial (Potter and others, 1980). Therefore, it may be possible that throughout Keasey sedimentation, slow and rapid deposition were taking place simultaneously in different portions of the Keasey basin.

Pittsburg Bluff Formation

The Pittsburg Bluff Formation overlies the Keasey Formation. Marine to brackish water, deltaic deposits (Warren and Norbisrath, 1946) of the Pittsburg Bluff Formation are 180 to 245 meters thick (Van Atta, 1971; Moore, 1976). While the lithology of the underlying Keasey Formation is dominated by mudstone, the Pittsburg Bluff Formation consists of distinctly coarser grained lithofacies. Van Atta (1971, p. 64) describes the Pittsburg Bluff Formation as follows:

> In the type locality, near Pittsburg, Oregon, along the Nehalem River, the Pittsburg Bluff Formation consists of massive fine grained arkosic to lithic arkosic clayey, tuffaceous concretionary sandstone beds.

The lithology described above, is exposed in intermittent outcrops along Oregon Highway 47 from Pittsburg to the boundary between sections 28 and 29, T. 6 N., R. 4 W. Similar lithofacies can be seen in the road cuts north of Mist. However, to the southwest, in Deep Creek area, and near Birkenfeld, the Pittsburg Bluff Formation consists of "well stratified, alternating gray shale and fine grained shaly sandstones" (Warren and Norbisrath, 1946; p. 230). Therefore it is apparent that the Pittsburg Bluff Formation southwest of Mist consists of strikingly different lithofacies than at the type locality. These two lithofacies are fairly well exposed in the study area, and each directly overlies the Keasey Formation. For the purpose of convenience and clarity, the lithofacies that are similar to those in the Deep Creek and Birkenfeld area are referred to as the laminated member (informal), and the lithofacies of the type locality as the siltstone member (informal).

Laminated Member. The laminated member is an areally extensive, mappable unit of the Pittsburg Bluff Formation consisting of dark gray to black, well stratified, discontinuous, parallel, thinly laminated mudstone (Figure 11) and interbedded laminated, fine grained sandstone. The discontinuous laminae within the mudstone are 1 to 2 mm thick on the average, and consist of carbonaceous to micaceous, fine grained sand or silt. The laminated mudstone weathers to a buff color identical to the weathered mudstone of the Keasey Formation, and therefore in weathered outcrops it is difficult to distinguish them. However, at various places, the laminated mudstone contains iron-stained, 3 to 4 cm wide, spherical concretions. These concretions are often hollow, but usually contain fine grained sand or silt.

The laminated member, especially in the lower part of the section, consists of intertonguing laminated

Figure 11. Typical, moderately weathered outcrop of the laminated member; note a hollow concretion near the center of the photo.

mudstone and gray sandstone. The sandstone interbeds are usually laminated. The carbonaceous to micaceous laminae are usually less than 2 mm thick, while the thickness of the sandstone interbeds varies from about 10 cm to 200 cm. A pebbly sandstone layer containing abundant mud pebbles and fossil shell fragments crops out at a logging road cut in the extreme northwestern corner of section 26, T. 6 N., R. 5 W. Penecontemporaneous slumping is also apparent in this outcrop.

The high mud:sand ratio, lack of burrowing organisms, and parallel, even lamination of the laminated member indicates sedimentation in a quiet water, low energy environment; an environment characteristically different from the siltstone member. One possible genesis of the laminated member may be that the thicker mud layers (interlayered with relatively thin sand layers) were deposited on the shelf where normal mud deposition was interrupted by transport of sand into the environment.

Siltstone Member. The siltstone member crops out in an arcuate belt roughly paralleling the Nehalem River in the study area. To the west and south of the Nehalem River loop (apart from a few outcrops of tuffaceous, lithic arkosic, medium to coarse grained sandstone) bioturbated siltstone and fine grained sandstone are predominant lithofacies. The siltstone appear to be devoid of any calcareous spherical concretions which are so common among the exposures along Oregon Highway 47 north of Pittsburg. Near the contact with the Keasey Formation, in section 16 and 17, T. 5 N., R. 4 W., in the Crooked Creek area, the Pittsburg Bluff Formation consists of bioturbated siltstone. From this area, the thickness of the siltstone member decreases westward and it is not present west of the boundary between R. 4 and 5 W. To the north of Mist, along Oregon Highway 47 and in sections 11, 14, and 15, T. 6 N., R. 5 W., well lithified, bioturbated, fossiliferous, fine grained sandstone and siltstone contain fairly abundant carbonized plant material and thin coal lenses. A one meter long thin coal lens is noted in a bluff along the Nehalem River in section 28, T. 6 N., R. 4 W. Warren and Norbisrath (1946) considered the thin tuff layers in the Pittsburg Bluff Formation, along Oregon Highway 47 north of Mist, to be typical of the upper part of the Formation. However, similar tuff layers are also present at the base of the Pittsburg Bluff Formation near the contact with the Keasey Formation.

Astoria Formation

North of Mist, along Oregon Highway 47, the Pittsburg Bluff Formation is overlain by loosely consolidated, tuffaceous, poorly sorted, clayey, fine grained sandstone, siltstone, and mudstone of the Astoria

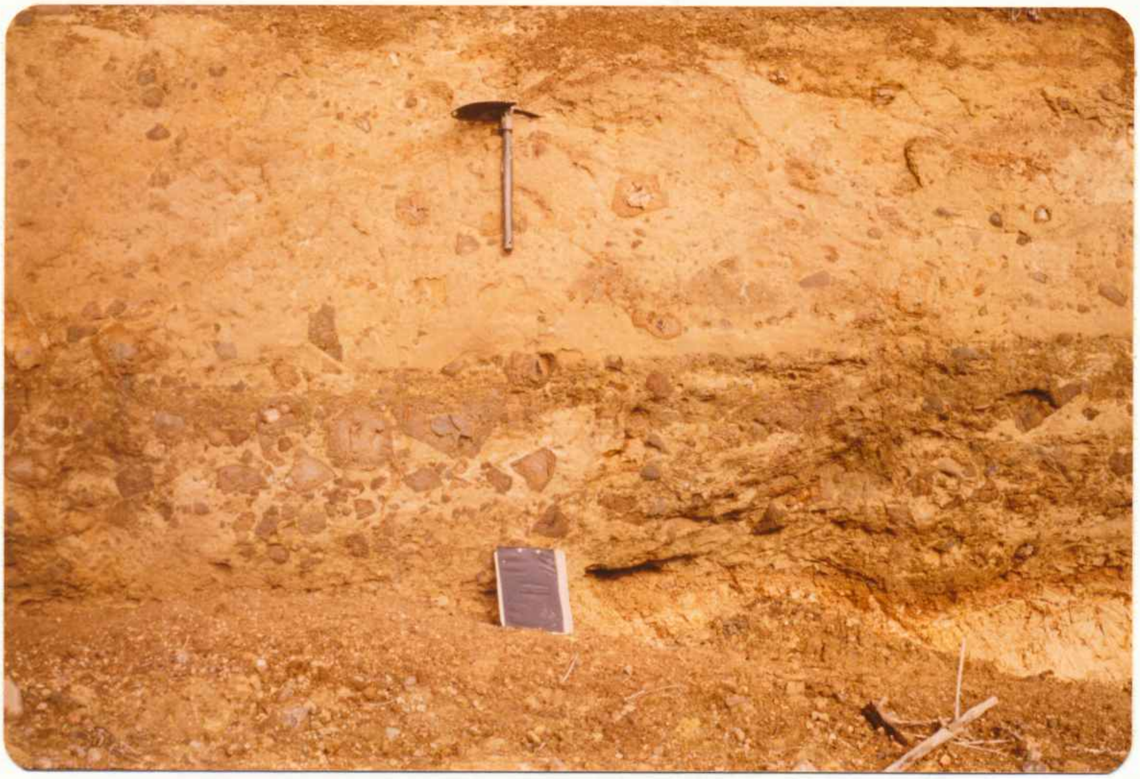
Formation, whose basal part consists of pebble lenses. A similar relationship is seen approximately 2 kilometers west of the above location in sections 2 and 11, T. 6 N., R. 5 W., where bioturbated, lithified siltstone and fine grained sandstone of the Pittsburg Bluff Formation are overlain by a sedimentary section of the Astoria Formation whose basal part consists of abundant pebble lenses overlain by interbedded micro cross-laminated, fine grained sandstone, siltstone, and mudstone. Basalt clast conglomerates and the basalt of the Columbia River Basalt Group cap the section. The pebble lenses at the base of the Astoria Formation at both the above locations consists of mud pebbles as well as (weathered) basalt pebbles.

Sediments overlying the Pittsburg Bluff Formation were named the Scappoose Formation by Warren and Norbisrath (1946, p. 232). They stated:

> The Scappoose Formation seems to rest disconformably on the underlying Pittsburg Bluff Formation and it is separated from it by a conglomerate of variable thickness.

These conglomerates are invariably composed of basalt clasts and the chemical analysis (Kelty, 1981) of these clasts, collected near Buxton, reveal them to be of middle Miocene Columbia River Basalt Group. The implied tectonic significance of the basalt clast conglomerate by Warren and Norbisrath (1946) appears to be erroneous as there are a number of basalt clast conglomerate layers at various stratigraphic horizons north of Mist, and these conglomerate layers are usually associated with the basalt flows of the Columbia River Basalt Group. Late Oligocene to early Miocene marine to brackish water sediments of the Scappoose Formation are overlain by sediments which at places contain middle Miocene basalt clasts, and referred to by Kelty (1981) as (middle Miocene) upper member (informal) of the Scappoose Formation. To this upper member (informal) of the Scappoose Formation, the name Astoria Formation is applied in this study. The Scappoose Formation, as defined by Warren and Norbisrath (1946), is not present in the study area.

Lithologically, the Astoria Formation consists of loosely consolidated, poorly sorted, tuffaceous, micaceous, lithic arkosic to quartzose sandstone, siltstone, and mudstone. Basalt clast conglomerates in the Astoria Formation appear to be predominantly composed of the Columbia River Basalt Group. Locally, as in the Mist gas field area, large angular basalt clasts and boulders are imbedded in the sediments (Figure 12), and they imply the presence of basaltic highs on the topography from which the basalt clasts and boulders were derived. Primary structures are well developed in the sediments of the Astoria Formation, and they are unlike those in any other formations in the study area. Trough cross-bedding, micro



<u>Figure 12</u>. Astoria Formation in the Mist field area; note the erosional botton contact, and relict angular clasts imbeded in the layer above the conglomerate layer.

cross, and climbing micro cross-laminations are among the primary structures observed.

The Astoria Formation rests unconformably on the Pittsburg Bluff Formation and the Keasey Formation. The contact between the Astoria Formation and the Keasey Formation is exposed in NE/4 section 25, T. 6 N., R. 4 W., and in the middle of section 2, T. 5 N., R. 5 W., where north-trending channels are lined with mud rip-ups. The thickness of the Astoria Formation increases towards the north along with a general coarsening of the grain size, increased abundance of basalt clast conglomerates, and an increase in the number and thickness of flows of the Columbia River Basalt Group. South of Mist, however, the Astoria Formation thins and laps onto the Keasey Formation.

The diversity of lithofacies ranging from conglom-rate to claystone, the primary structure, and the subaerial and pillow basalt that is enclosed in the Astoria Formation indicates deposition in a shallow, nearshore environment.

Columbia River Basalt Group

The Columbia River Basalt Group (CRBG) in the study area is represented by low magnesium flows of the Grande Ronde Basalt and the Frenchman Springs Member of the Wanapum Basalt. In the south central part of section 6,

T. 5 N., R. 4 W., a weathered low magnesium Grande Ronde flow rests on basalt clast conglomerate (Figure 13) which in turn overlies a coarse sand. The thickness of the Pittsburg Bluff Formation (siltstone member), upon which this flow rests, is less than approximately 20 meters. Northeast of Mist, in section 6, T. 6 N., R. 4 W., subaerial basalt flows of low magnesium Grande Ronde Formation overlie cross-bedded, coarse sandstone. The baked zone is about 6 to 10 cm thick. To the west in section 3, T. 6 N., R. 5 W., pillow basalt of the Frenchman Springs Member of the Wanapum Basalt rests on a thick layer of conglomerate. Chemical analyses of the basalts are listed in Table-1, and discussed in the "Geochemistry" section.

The course of the CRBG flows was governed by existing paleodrainages and topographic lows. Pillow basalt of the Frenchman Springs Member and palagonite-containing coarse sandstone upon which the Grande Ronde flow rests are indicative of interaction of CRBG flows with the marine environment. The broad, shallow embayment into which the CRBG flows are confined may have been approximately 20 kilometers wide at the nearest points in southwestern Washington and northwestern Oregon. The width of this embayment increases towards the west.

The Frenchman Springs Member of the Wanapum Basalt rests at approximately the same topographic elevation as

Figure 13. Basalt-clast conglomerate at the base of weathered Grande Ronde flow.

the Grande Ronde Basalt north of Mist. However, the Frenchman Springs Member is placed higher in the CRBG section than the Grande Ronde Basalt. This may indicate the infilling of the topographic lows by the earlier flows and development of topography over them before the arrival of the later flows. These later flows (e.g., of Frenchman Springs) then, occupied the existing topographic lows.

GEOCHEMISTRY

Whole-rock major-element analyses of eight basalt samples were made by Peter R. Hooper of Washington State University. Concentration of major elements are listed in Table I. All except one sample belong to either the Grande Ronde Basalt or the Frenchman Springs Member of the Wanapum Basalt (Figure 14). The different sample, from a core from the Texaco "Clark and Wilson" well from 8479 foot depth (core # 135) is probably related to the Tillamook Volcanics.

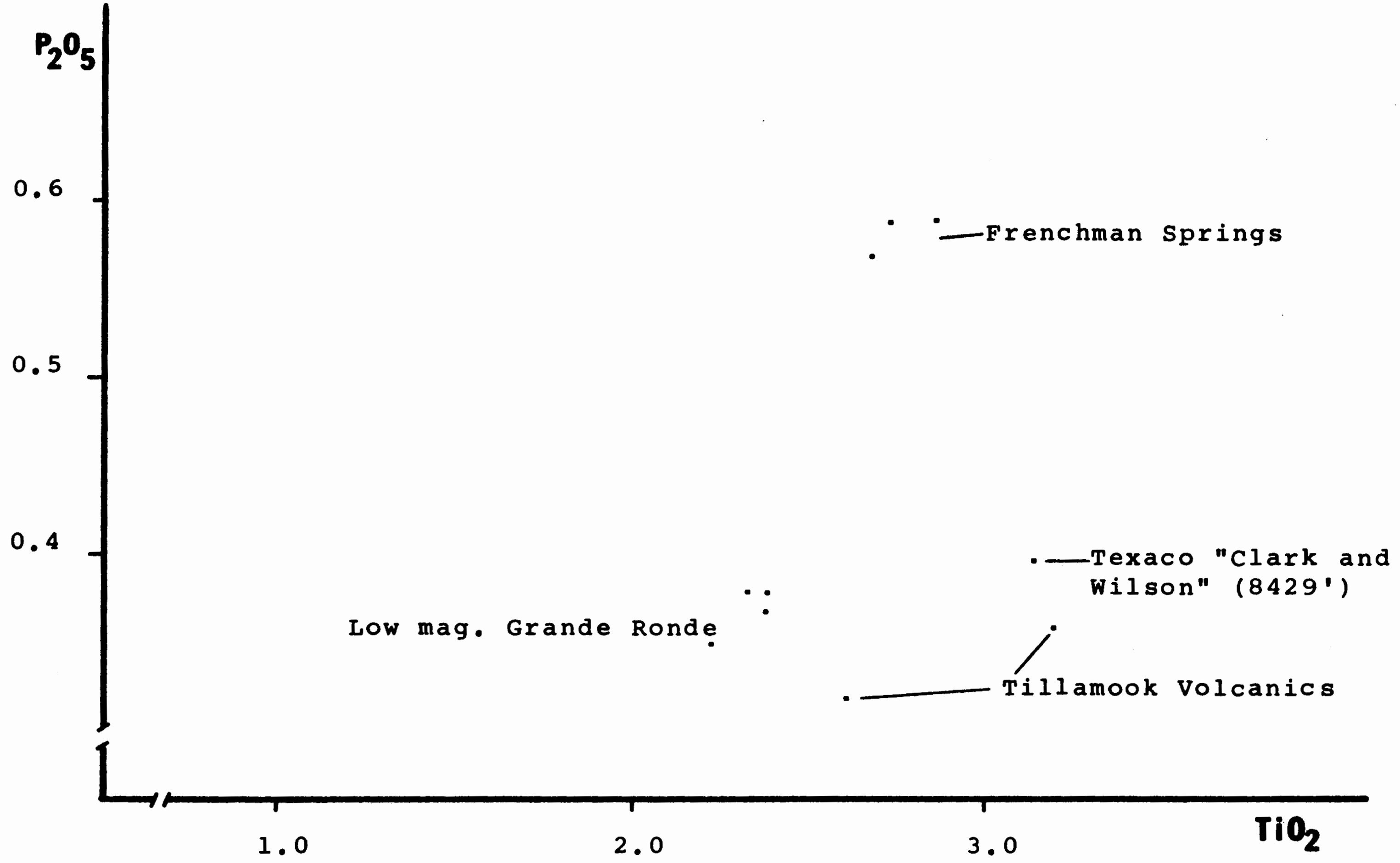
Fifty three sedimentary and three basalt samples were analyzed by the author for minor and trace element concentrations through instrumental neutron activation analysis (INAA). The concentrations of the elements are listed in Table II. No previous data on minor or trace element concentrations in these formations exists. Approximately 1 gm of each disaggregated sample was analyzed. The selected samples were sieved through a 200 mesh screen and 1 gm of the resulting silt and clay fraction of each was analyzed along with the whole rock samples. No consistent enrichment or depletion of elements between the whole rock and 200 mesh fraction of the selected samples was observed. The difference in the

TABLE I

MAJOR-OXIDE CHEMICAL ANALYSES OF BASALT SAMPLES.

	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
Texaco C&W	50.35	16.31	3.14	2.00	10.47	0.20	10.08	4.15	0.50	2.39	0.40
6-5-4A	55.99	15.46	2.37	2.00	8.36	0.34	7.44	3.46	2.03	2.18	0.37
6-5-4B	56.68	15.21	2.21	2.00	8.61	0.31	7.05	3.56	1.98	2.03	0.35
6-5-4C	56.25	15.72	2.32	2.00	8.13	0.22	7.33	3.54	1.92	2.21	0.38
6-5-4D	54.40	15.39	2.38	2.00	8.90	0.27	7.21	3.13	1.88	2.08	0.38
*3-6-5	52.41	11.38	2.85	7.38	8.45	0.24	8.44	4.18	1.13	2.96	0.59
*3-6-5A	52.31	13.30	2.73	6.70	7.67	0.37	8.30	3.49	1.50	3.03	0.59
*3-6-5B	53.45	13.26	2.66	6.48	7.43	0.34	7.90	3.44	1.30	3.16	0.57

* international standard



<u>Figure 14</u>. P_2O_5 versus TiO diagram of basalt samples (Tillamook Volcanics data from Cameron, 1980).

TABLE II

TRACE AND MINOR ELEMENT CONCENTRATIONS OF ANALYSED SAMPLES

	NA %	±	K %	±	FE %	±	LA PPM	±	SM PPM	±
COWLITZ FORMATION										
22-4-5	2.22	0.01	1.06	0.18	2.80	0.50	50.30	1.40	9.08	0.19
6-3-5	1.26	0.01	1.80	0.20	4.50	0.60	45.90	1.30	9.05	0.18
6-3-5A	0.86	0.0	1.47	0.15	4.50	0.50	36.50	1.0	9.14	0.16
32-3-5	0.85	0.0	1.57	0.16	5.8	0.5	35.80	1.0	8.09	0.14
32-3-5A	1.36	0.01	1.70	0.20	3.60	0.50	42.40	1.30	8.40	0.17
KEASEY FORMATION										
25-6-5	0.71	0.0	0.59	0.08	4.0	0.50	130.0	3.0	44.0	0.60
25-6-5A	1.25	0.01	0.77	0.11	4.70	0.70	115.0	3.0	52.90	0.70
20-6-4	1.11	0.01	0.73	0.10	4.20	0.50	10.10	0.50	3.60	0.10
20-6-4A	1.31	0.01	0.72	0.13	5.0	0.4	14.50	0.60	4.75	0.12
2-5-5	0.56	0.0	0.43	0.06	2.9	0.4	103.0	2.0	39.0	0.50
23-6-5	1.39	0.01	0.90	0.13	5.10	0.60	16.50	0.70	4.83	0.12
23-6-5A	1.24	0.01	0.82	0.11	3.40	0.50	11.70	0.60	3.79	0.10
33-6-4	1.46	0.01	0.84	0.12	5.70	0.60	15.7	0.60	5.66	0.13
PITTSBURG BLUFF FORMATION										
23-5-4	1.85	0.01	1.40	0.18	4.30	0.70	36.10	1.10	7.31	0.15
23-5-4A	1.76	0.01	0.83	0.15	4.76	0.50	89.0	2.0	16.8	0.30
23-5-4B	1.81	0.01	1.30	0.18	4.20	0.60	14.70	0.30	6.45	0.15
28-6-4	1.43	0.01	1.40	0.17	3.40	0.50	26.60	0.90	10.16	0.16
12-6-5	1.55	0.01	1.15	0.14	3.40	0.50	27.60	0.90	6.55	0.15
12-6-5A	1.52	0.01	1.48	0.20	2.8	0.50	24.70	0.80	7.03	0.15
12-6-5B	1.64	0.01	1.52	0.18	2.5	0.5	25.30	0.80	5.17	0.13
12-6-5C	1.63	0.01	1.10	0.15	4.90	0.60	20.10	0.80	5.54	0.13
12-6-5D	1.66	0.01	1.09	0.16	3.60	0.40	36.9	1.10	5.07	0.13
11-6-5	1.60	0.01	1.09	0.16	3.60	0.40	36.9	1.10	12.21	0.19
4-5-4	1.03	0.01	1.82	0.20	4.10	0.40	30.0	0.90	7.13	0.14
ASTORIA FORMATION										
12-6-5E	0.89	0.01	1.03	0.14	3.80	0.60	103.0	3.0	33.0	0.50
12-6-5F	0.85	0.0	0.93	0.11	4.50	0.5	105.0	2.0	35.10	0.50
12-6-5G	0.53	0.0	0.91	0.10	5.40	0.50	23.90	0.70	5.51	0.11
12-6-5H	0.06	0.0	0.06	0.02	7.10	0.30	17.80	0.60	4.60	0.09
6-6-4	2.81	0.02	0.0	0.0	4.50	0.50	19.0	0.80	6.01	0.14
3-6-5	0.23	0.0	0.62	0.07	7.50	0.40	33.90	1.0	9.93	0.16
3-6-5A	0.16	0.0	0.35	0.04	8.60	0.40	38.8	1.0	11.79	0.17
2-6-5	0.22	0.0	0.63	0.07	5.10	0.40	32.10	0.90	6.67	0.12
2-6-5A	0.38	0.0	0.67	0.07	4.90	0.40	43.0	1.10	8.83	0.14
2-6-5B	0.14	0.0	0.70	0.07	4.60	0.30	20.30	0.60	4.91	0.09
25-6-5B	0.15	0.0	1.19	0.13	3.80	0.30	26.70	0.80	4.89	0.10
25-6-5C	0.16	0.0	0.90	0.09	4.40	0.30	35.5	0.90	6.57	0.11
25-6-5D	0.14	0.0	1.27	0.14	2.60	0.30	23.50	0.70	4.09	0.09
30-6-4	0.69	0.0	0.98	0.11	3.70	0.50	37.6	1.0	9.76	0.16
30-6-4A	0.69	0.0	0.78	0.09	4.20	0.50	43.4	1.20	10.49	0.18
30-6-4B	0.65	0.0	0.93	0.10	4.20	0.50	55.6	1.40	14.90	0.20
2-5-5A	1.17	0.01	1.60	0.18	3.20	0.50	26.80	0.90	5.96	0.13
2-5-5B	0.82	0.01	0.96	0.11	4.80	0.50	44.40	1.20	10.10	0.17
2-5-5C	0.98	0.01	1.50	0.17	3.0	0.50	22.40	0.80	4.48	0.13
COLUMBIA RIVER BASALT GROUP										
6-5-4	1.62	0.01	0.65	0.11	10.10	0.60	21.6	0.70	7.10	0.14
6-5-4A	2.37	0.01	1.08	0.19	10.70	0.60	23.50	0.90	7.30	0.17
6-6-4A	2.84	0.02	1.02	0.20	7.90	0.60	30.0	1.0	8078	0.17
TEXACO 'CLARK AND WILSON'										
915'	2.25	0.01	1.08	0.21	5.0	0.50	18.20	0.70	5.46	0.13
2076'	2.35	0.01	1.06	0.18	6.60	0.60	13.20	0.60	4.13	0.12
3092'	1.95	0.01	1.72	0.21	2.60	0.20	47.0	1.3	9.16	0.18
COLUMBIA COUNTY NO.1										
180'	1.61	0.01	1.14	0.15	5.20	0.50	18.30	0.70	5.22	0.12
780'	1.98	0.01	0.74	0.13	4.80	0.70	14.70	0.70	5.33	0.14
1170'	1.91	0.01	0.65	0.13	6.60	1.0	13.50	0.80	4.63	0.15
1440'	1.97	0.01	0.98	0.15	5.60	1.10	14.80	0.90	4.92	0.19
2130'	1.49	0.01	1.32	0.17	6.10	1.0	20.90	1.0	5.67	0.19
LONGVIEW FIBER NO.1, RD 1										
1110'	1.80	0.01	0.48	0.12	4.0	0.70	12.50	0.70	4.68	0.14
1470'	2.04	0.01	0.93	0.17	4.80	0.50	14.60	0.70	4.41	0.12
STANDARDS										
W-1T	4.82	0.02	0.0	0.0	8.72	0.23	9.80	0.30	3.60	0.07
W-1B	1.66	0.01	0.39	0.12	8.70	0.20	9.80	0.30	3.60	0.07
ARCO T	2.38	0.01	1.63	0.18	11.13	0.50	40.0	1.10	10.39	0.16
ARCO B	2.44	0.01	1.66	0.20	11.10	0.30	39.3	0.9	10.69	0.14
O-16 T	3.20	0.02	3.20	0.50	0.0	0.0	73.0	2.0	12.40	0.20
O-16 B	3.20	0.02	3.20	0.42	1.39	0.17	34.3	0.90	6.52	0.12

TABLE II (CON'T)

	SC PPM	±	YB NORM	±	LU PPM	±	TH PPM	±
	COWLITZ FORMATION							
22-4-5	11.20	0.40	3.0	0.90	0.0	0.0	13.0	2.0
6-3-5	13.90	0.60	0.22	0.06	0.0	0.0	11.0	4.0
6-3-5A	13.90	0.50	2.74	0.83	0.0	0.0	9.9	2.30
32-3-5	13.70	0.50	0.0	0.0	0.0	0.0	12.0	2.0
32-3-5A	12.70	0.40	0.21	0.04	0.0	0.0	12.02	3.76
	KEASEY FORMATION							
25-6-5	20.90	0.50	1.00	0.07	2.32	0.59	0.0	0.0
25-6-5A	26.30	0.70	10.92	1.88	1.78	0.33	0.0	0.0
20-6-4	13.30	0.50	0.0	0.0	0.0	0.0	0.0	0.0
20-6-4A	17.20	0.40	0.0	0.0	0.0	0.0	0.0	0.0
2-5-5	15.30	0.40	13.80	2.0	2.18	0.27	0.0	0.0
23-6-5	18.90	0.50	0.19	0.05	0.0	0.0	0.0	0.0
23-6-5A	13.80	0.50	0.0	0.0	0.0	0.0	0.0	0.0
33-6-4	20.30	0.50	0.0	0.0	0.0	0.0	0.0	0.0
	PITTSBURG BLUFF FORMATION							
23-5-4	13.50	0.50	0.23	0.07	0.0	0.0	9.76	3.76
23-5-4A	19.0	0.50	6.08	1.23	0.88	0.22	24.68	3.82
23-5-4B	12.10	0.50	0.0	0.0	0.0	0.0	9.44	3.52
28-6-4	10.40	0.40	4.89	1.05	0.0	0.0	10.30	2.29
12-6-5	14.60	0.50	0.21	0.05	0.81	0.27	0.0	0.0
12-6-5A	13.90	0.50	3.55	0.96	0.0	0.0	9.40	2.34
12-6-5B	12.80	0.50	0.19	0.05	0.0	0.0	0.0	0.0
12-6-5C	12.0	0.50	0.0	0.0	0.0	0.0	10.67	2.92
12-6-5D	18.80	0.50	0.0	0.0	0.0	0.0	0.0	0.0
11-6-5	17.90	0.50	5.15	1.01	0.70	0.20	0.0	0.0
4-5-4	14.80	0.40	3.12	0.80	0.0	0.0	10.73	2.03
	ASTORIA FORMATION							
12-6-5E	20.90	0.50	0.72	0.06	1.63	0.47	0.0	0.0
12-6-5F	21.20	0.60	12.47	1.86	1.71	0.25	11.53	2.41
12-6-5G	22.20	0.50	0.0	0.0	0.0	0.0	0.0	0.0
12-6-5H	28.50	0.50	0.15	0.02	0.0	0.0	6.35	2.14
6-6-4	17.10	0.50	0.0	0.0	0.0	0.0	0.0	0.0
3-6-5	20.0	0.40	0.29	0.04	0.96	0.28	0.0	0.0
3-6-5A	23.6	0.40	5.74	0.94	0.82	0.15	0.0	0.0
2-6-5	23.90	0.40	0.15	0.03	0.0	0.0	10.71	3.28
2-6-5A	23.70	0.56	3.63	0.76	0.55	0.17	15.79	2.13
2-6-5B	24.10	0.40	2.16	0.51	0.39	0.12	8.84	1.44
25-6-5B	16.0	0.40	0.14	0.03	0.46	0.17	10.02	3.01
25-6-5C	17.3	0.40	2.66	0.58	0.43	0.13	12.53	1.70
25-6-5D	12.90	0.30	0.14	0.03	0.0	0.0	10.70	3.15
30-6-4	26.3	0.50	4.50	0.91	0.82	0.20	8.87	2.07
30-6-4A	27.6	0.50	0.33	0.05	0.74	0.27	12.31	3.98
30-6-4B	28.40	0.50	5.41	1.01	0.84	0.20	10.03	2.74
2-5-5A	13.60	0.50	0.0	0.0	0.74	0.28	0.0	0.0
2-5-5B	21.80	0.60	4.25	0.89	0.60	0.19	15.32	2.28
2-5-5C	12.10	0.50	0.0	0.0	0.0	0.0	8.88	3.41
	COLUMBIA RIVER BASALT GROUP							
6-5-4	32.90	0.60	3.98	0.97	0.0	0.0	0.0	0.0
6-5-4A	34.70	0.60	0.0	0.0	0.0	0.0	0.0	0.0
6-6-4A	36.20	0.70	0.29	0.06	0.90	0.33	0.0	0.0
	TEXACO "CLARK AND WILSON"							
915'	17.30	0.60	0.0	0.0	0.0	0.0	0.0	0.0
2076'	26.6	0.60	0.0	0.0	0.0	0.0	0.0	0.0
3092'	13.20	0.40	0.0	0.0	0.0	0.0	14.02	2.47
	COLUMBIA COUNTY NO.1							
180'	17.0	0.50	0.0	0.0	0.0	0.0	0.0	0.0
780'	18.80	0.70	3.71	1.19	0.0	0.0	0.0	0.0
1170'	20.90	1.0	0.0	0.0	0.0	0.0	0.0	0.0
1440'	19.90	1.0	0.0	0.0	0.0	0.0	0.0	0.0
2130'	21.10	0.90	0.0	0.0	0.0	0.0	0.0	0.0
	LONGVIEW FIBER NO.1, RD.1							
1110'	15.40	0.80	0.0	0.0	0.0	0.0	0.0	0.0
1470'	15.10	0.50	0.0	0.0	0.0	0.0	0.0	0.0
	STANDARDS							
W-1T	35.1	0.30	0.12	0.02	0.0	0.0	0.0	0.0
W-1B	35.1	0.30	2.10	0.38	0.27	0.07	8.13	0.84
ARCO T	25.5	0.40	0.26	0.04	0.65	0.21	6.80	2.56
ARCO B	26.70	0.20	4.21	0.62	0.65	0.08	6.80	0.69
0-16 T	3.90	0.30	0.28	0.06	0.79	0.29	10.74	3.52
0-16 B	3.47	0.15	4.31	0.73	0.73	0.11	10.41	1.10

TABLE II (CON'T)

	CO PPM		CR NORM		BR NORM		AS NORM	
	COWLITZ FORMATION							
22-4-5	0.0 ±	0.0	180.0 ±	30.0	0.0 ±	0.0	0.0 ±	0.0
6-3-5	0.0	0.0	0.0	0.0	0.0	0.0	0.56	0.11
6-3-5A	0.0	0.0	0.0	0.0	0.41	0.05	1.00	0.12
32-3-5	0.0	0.0	0.0	0.0	0.0	0.0	1.17	0.13
32-3-5A	0.0	0.0	0.0	0.0	0.0	0.0	0.41	0.11
	KEASEY FORMATION							
25-6-5	0.0	0.0	0.0	0.0	0.94	0.14	0.75	0.12
25-6-5A	0.0	0.0	0.0	0.0	0.44	0.07	0.74	0.14
20-6-4	0.0	0.0	0.0	0.0	0.45	0.09	0.67	0.11
20-6-4A	0.0	0.0	88.1	23.3	0.37	0.05	0.07	0.11
2-5-5	0.0	0.0	0.0	0.0	0.55	0.06	0.58	0.08
23-6-5	0.0	0.0	0.0	0.0	0.35	0.09	0.81	0.14
23-6-5A	0.0	0.0	0.0	0.0	0.69	0.11	0.72	0.12
33-6-4	0.0	0.0	0.0	0.0	0.43	0.06	0.52	0.11
	PITTSBURG BLUFF FORMATION							
23-5-4	0.0	0.0	0.0	0.0	0.0	0.0	0.56	0.11
23-5-4A	0.0	0.0	176.6	48.1	0.0	0.0	0.48	0.12
23-5-4B	0.0	0.0	0.0	0.0	1.07	0.15	0.52	0.12
28-6-4	0.0	0.0	0.0	0.0	0.0	0.0	0.53	0.14
12-6-5	0.0	0.0	0.0	0.0	0.43	0.12	1.22	0.15
12-6-5A	0.0	0.0	0.0	0.0	0.25	0.05	1.08	0.14
12-6-5B	0.0	0.0	0.0	0.0	0.46	0.10	1.03	0.15
12-6-5C	0.0	0.0	0.0	0.0	0.39	0.06	0.78	0.12
12-6-5D	0.0	0.0	0.0	0.0	0.88	0.14	1.04	0.15
11-6-5	0.0	0.0	0.0	0.0	1.00	0.10	0.73	0.14
4-5-4	0.0	0.0	0.0	0.0	0.16	0.04	0.49	0.10
	ASTORIA FORMATION							
12-6-5E	0.0	0.0	0.0	0.0	0.58	0.10	0.0	0.0
12-6-5F	0.0	0.0	0.0	0.0	0.44	0.05	0.0	0.0
12-6-5G	0.0	0.0	0.0	0.0	0.63	0.09	0.32	0.07
12-6-5H	119.52	8.16	0.0	0.0	0.53	0.07	0.42	0.06
6-6-4	0.0	0.0	0.0	0.0	0.29	0.06	0.0	0.0
3-6-5	23.29	5.62	0.0	0.0	0.0	0.0	0.0	0.0
3-6-5A	22.24	5.44	0.0	0.0	0.0	0.0	0.0	0.0
2-6-5	0.0	0.0	0.0	0.0	0.25	0.05	0.26	0.06
2-6-5A	0.0	0.0	111.0	25.2	0.18	0.03	0.26	0.07
2-6-5D	0.0	0.0	16.68	4.86	0.0	0.0	0.25	0.05
25-6-5B	0.0	0.0	66.6	16.8	0.0	0.0	0.23	0.05
25-6-5C	0.0	0.0	71.3	19.1	0.09	0.02	0.17	0.05
25-6-5D	0.0	0.0	0.0	0.0	0.13	0.03	0.20	0.05
30-6-4	0.0	0.0	29.14	7.18	0.0	0.0	0.67	0.09
30-6-4A	0.0	0.0	0.0	0.0	0.0	0.0	0.61	0.09
30-6-4B	0.0	0.0	36.82	7.68	0.0	0.0	1.51	0.15
2-5-5A	0.0	0.0	0.0	0.0	0.02	0.0	0.0	0.0
2-5-5B	0.0	0.0	0.0	0.0	0.75	0.09	0.73	0.11
2-5-5C	0.0	0.0	0.0	0.0	0.50	0.20	1.0	0.11
	COLUMBIA RIVER BASALT GROUP							
6-5-4	41.30	8.24	0.0	0.0	0.0	0.0	0.0	0.0
6-5-4A	39.82	7.96	0.0	0.0	0.0	0.0	0.0	0.0
[illegible]-6-4A	39.02	8.72	0.0	0.0	0.0	0.0	0.0	0.0
	TEXACO "CLARK AND WILSON"							
915'	0.0	0.0	113.0	30.5	0.30	0.06	0.88	0.14
2076'	26.83	7.52	0.0	0.0	0.0	0.0	0.50	0.13
3092'	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	COLUMBIA COUNTY NO.1							
180'	0.0	0.0	0.0	0.0	0.0	0.0	0.93	0.15
780'	0.0	0.0	0.0	0.0	0.40	0.08	0.90	0.15
1170'	0.0	0.0	0.0	0.0	0.59	0.13	0.68	0.15
1440'	0.0	0.0	0.0	0.0	0.40	0.10	0.69	0.16
2130'	0.0	0.0	0.0	0.0	0.52	0.13	1.23	0.18
	LONGVIEW FIBER NO.1, RD.1							
1110'	0.0	0.0	0.0	0.0	0.46	0.08	0.63	0.14
1470'	0.0	0.0	0.0	0.0	0.32	0.10	0.74	0.14
	STANDARDS							
W-1T	47.0	3.32	114.0	14.8	0.0	0.0	0.0	0.0
W-1B	47.0	3.06	114.0	11.9	0.0	0.0	0.0	0.0
ARCO T	32.39	6.20	0.0	0.0	0.0	0.0	0.0	0.0
ARCO B	32.10	2.54	0.0	0.0	0.0	0.0	0.0	0.0
0-16 T	0.0	0.0	0.0	0.0	0.99	0.19	0.0	0.0
0-16 B	0.0	0.0	0.0	0.0	0.32	0.04	0.36	0.11

grain size of the formations (e.g. the Keasey and Pittsburg Bluff Formations) necessitated whole rock and 200 mesh fraction of the samples.

The experimental geochemical analyses of the sediments were performed to determine if any of the formations could be geochemically defined. Provenance, environment of deposition, and post depositional processes presumably dictate the bulk chemical compositions of the sedimentary rocks, and of these three, provenance probably has a greater effect on composition than the other factors (Potter and others, 1980).

Only a few elements are common in a majority of the samples, therefore, the elements which are detected in the majority of the samples are discussed here. Figure 15 is plots of elements which are common to almost all of the samples. The concentration of five elements in all the samples is plotted against the formations. There is a wide range of concentration for each of the elements, and this general overlap of concentration is common for all the formations. For example, the sodium concentration for the Cowlitz and Keasey samples shows an overlap, but the overlap between the Pittsburg Bluff and Astoria Formations samples is minimal. Potassium concentration for the Cowlitz is much higher than the Keasey samples. The same is true for the lanthanum to samarium ratio of the two formations. Higher scandium concentration separates the

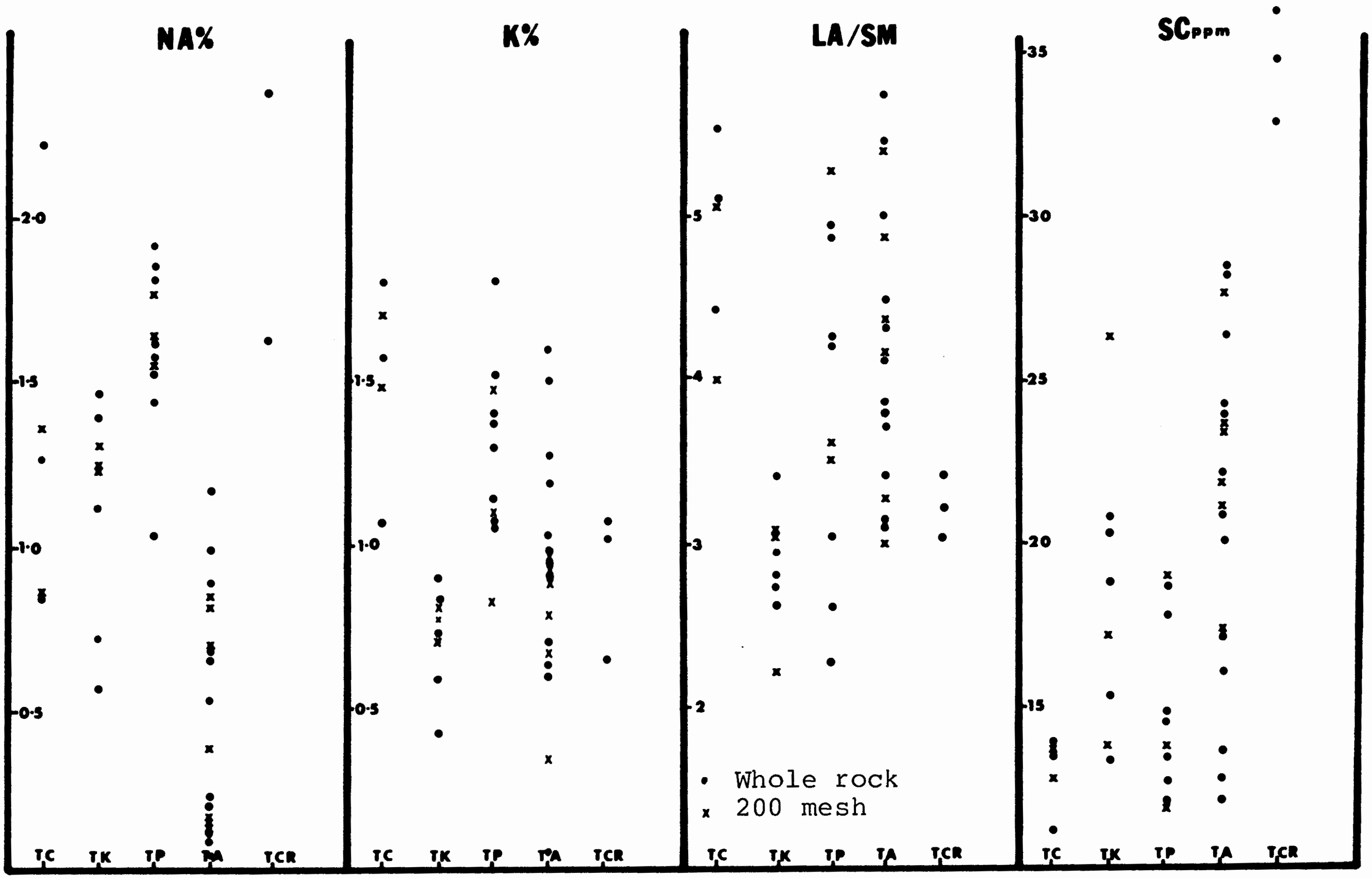


Figure 15. Concentrations of Na, K, Sc and the ratio La/Sm plotted against the formations, TC=Cowlitz, TK=Keasey, TP=Pittsburg Bluff, TA=Astoria TCR= Columbia River basalt.

CRBG from the sediments, while the concentration of scandium for the Astoria Formation is skewed towards the CRBG values. Generally low concentration of sodium and potassium for the Astoria Formation may be due to leaching, as a majority of the samples analyzed were weathered. The sodium versus potassium plot (Figure 16) for whole rock samples indicate a general grouping of the formations. The lanthanum to samarium ratio versus potassium plot (Figure 17), separates the Keasey from Cowlitz Formation.

The Cowlitz Formation has a higher concentration of potassium compared to the Keasey Formation. This fact is further supported by the petrographic analyses of the Tertiary rocks of the Nehalem River area (Van Atta, 1971). The Cowlitz Formation has relatively higher amount of potassium feldspar compared to any of the other formations. Therefore, higher potassium concentration in the Cowlitz rocks implies that the provenance for the arkosic sediments of the Cowlitz Formation includes granitic and metamorphic rocks (primary source of potassium). Granite has relatively higher concentration of lanthanum and lower concentration of scandium compared to basalt and andesite (Gordon and others, 1968). The Keasey Formation has a lower concentration of lanthanum and potassium, and it generally contains higher proportion of andesitic and basaltic rock fragments and volcanic glass (Van Atta, 1971). Therefore, petrographic and geochemical evidence suggests

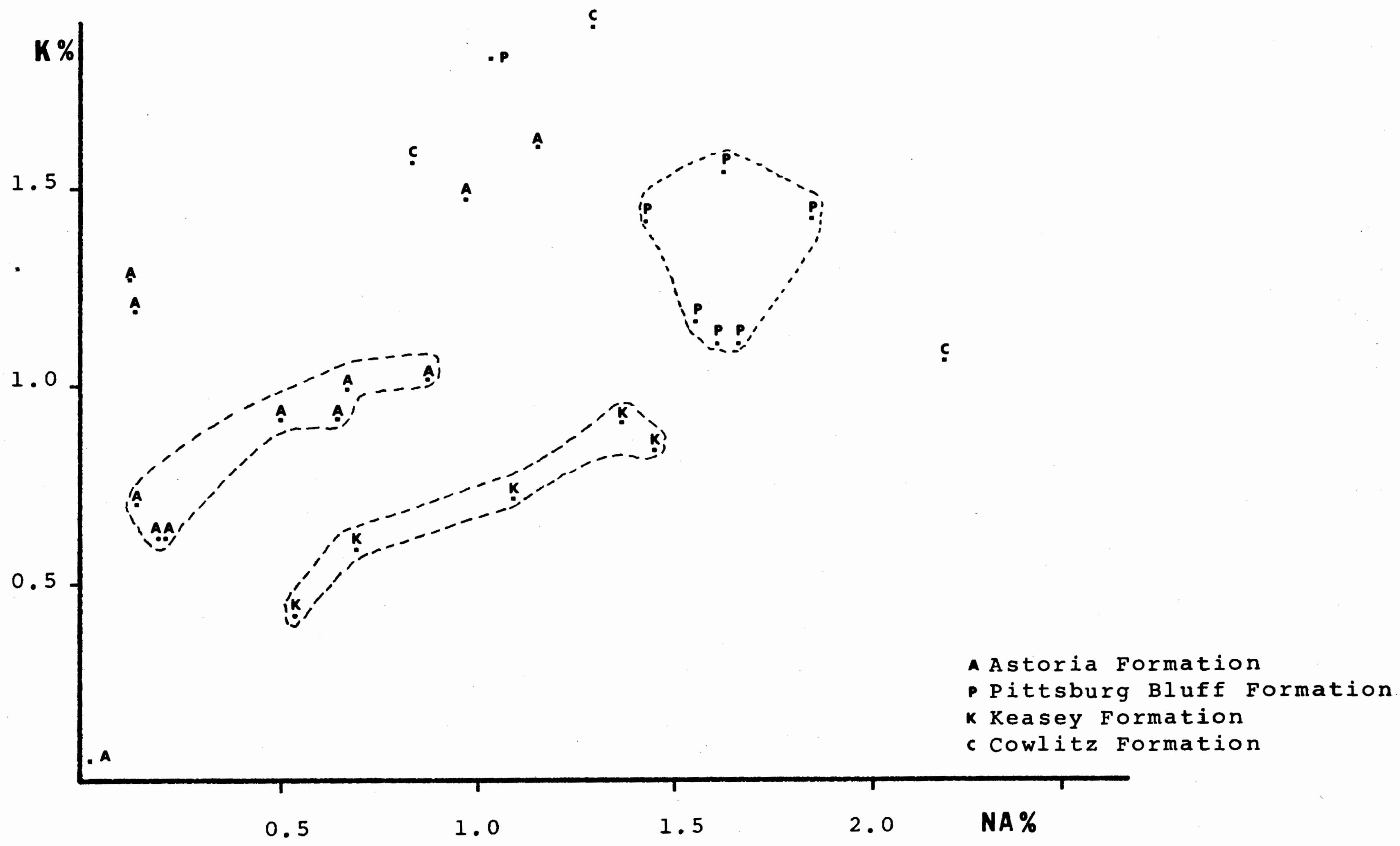
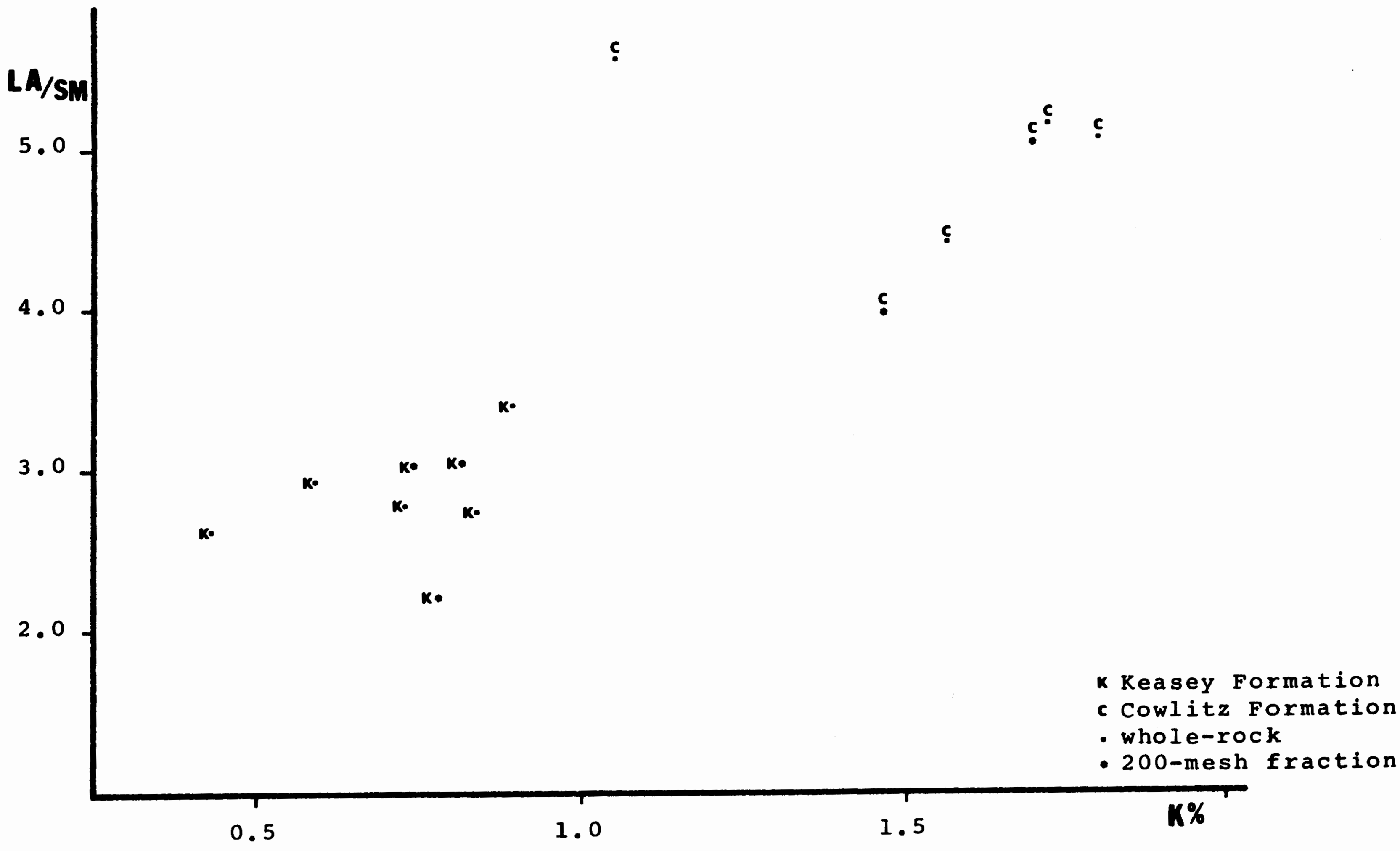


Figure 16. Potassium versus Sodium plot.



<u>Figure 17</u>. Lanthanum to Samarium ratio versus Potassium plot.

greater influence of volcanic component in the provenance of the Keasey Formation compared to the Cowlitz Formation. Therefore, a major break between a granitic-metamorphic dominated provenance and volcanic component dominated provenance occurs between the Cowlitz and the Keasey Formations.

The other major change in the provenance is probably seen in the rocks of the Astoria Formation. The CRBG has a much higher concentration of scandium than the sediments. Among the sediments analyzed, only the Astoria Formation samples have consistently higher scandium values. The Astoria Formation samples that have highest scandium concentration are pebbly sandstones (sample nos. 12-6-5H, 30-6-4B). Some of the pebbles in these sandstone are weathered basalt pebbles and thus, explains the higher scandium concentration, and influence of flood basalt in the provenance of the Astoria Formation.

The geochemical analyses, along with petrographic evidence (Van Atta, 1971) suggests three probable major provenances for the Tertiary sedimentary rocks in the Nehalem River area. Graphic illustration of these three major provenances is shown in Figure 18, where lanthanum to samarium ratio is plotted against scandium. Among the three sedimentary groups, one consists exclusively of some of the samples from the Astoria Formation, while the remaining two groups consist of Keasey and Cowlitz

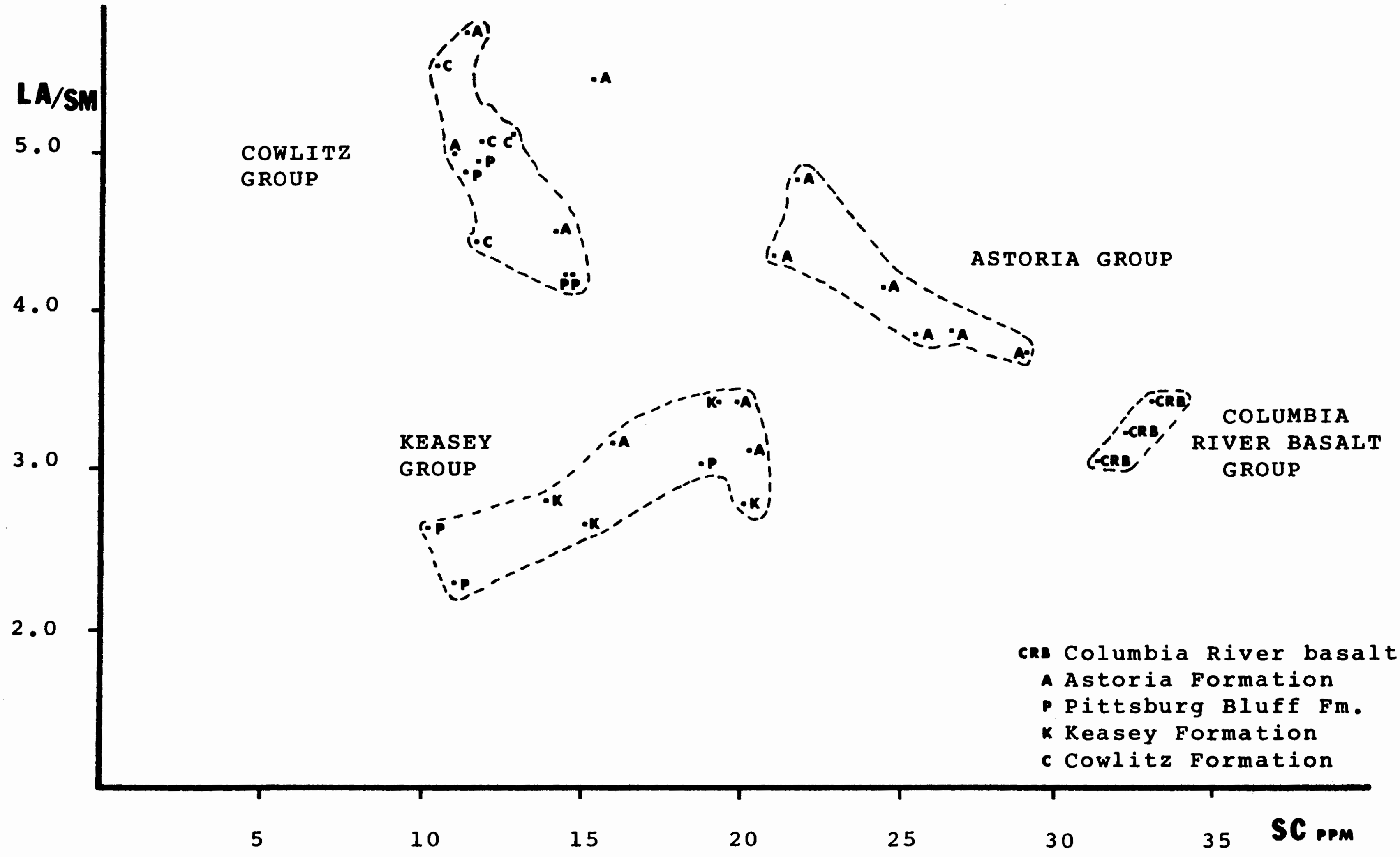


Figure 18. Lanthanum to Samarium ratio versus Scandium plot.

Formations, and each includes samples from the Pittsburg Bluff and Astoria Formations. The samples that plot in the Cowlitz group may imply the influence of granitic-metamorphic detritus in the rocks, while the samples that plot with the Keasey group may indicate the dominance of volcanic component over granitic-metamorphic component in the rocks.

Three samples from the cores of the Texaco "Clark and Wilson" well, five cuttings from the Columbia County No. 1, and two cuttings from the first re-drill of Longview Fiber No. 1 were analyzed. The result however, is inconclusive probably because (1) INAA is a very sensitive technique, and as the size of the cuttings is small, the cuttings are possibly contaminated by the drilling fluids, (2) the cuttings may be out of place, and (3) the cuttings are fresh compared to slightly weathered surface samples.

In conclusion, the combination of lithology and geochemistry appears to delineate the Tertiary formations in the study area. However, the sedimentary rocks are geochemically inhomogeneous compared to the igneous rocks, and therefore, the conclusions arrived at from the limited analyses in this study may be refuted or refined by further analyses.

STRUCTURE

The Oregon Coast Range is a distinctive structural province marked by a positive gravity anomaly (Figure 19). A north-trending, eastward sloping, steep gravity gradient on the east margin suggests that major faulting may separate the Coast Range from the Willamette Valley downwarp or graben (Bromery and Snavely, 1964). Early to middle Eocene oceanic crust underlies the Coast Range, and it is considered to be the basement of the Oregon Coast Range (Snavely and others, 1980).

In northwestern Oregon, the north-plunging Tillamook anticlinal upwarp (arch) has produced northerly regional dips and outcrops of progressively younger formations towards the north away from the core of the Tillamook highlands. In southwestern Washington, progressively younger formations crop out towards the south away from the Willapa Hills upwarp producing southerly regional dips in the eastern Willapa Hills area (Wells, 1981). Therefore, southerly regional dips in southwestern Washington and northerly regional dips in northwestern Oregon have produced an east-west trending synclinal trough, where the youngest rocks are confined (Figure 3). The distribution of younger units (Miocene) appears to be

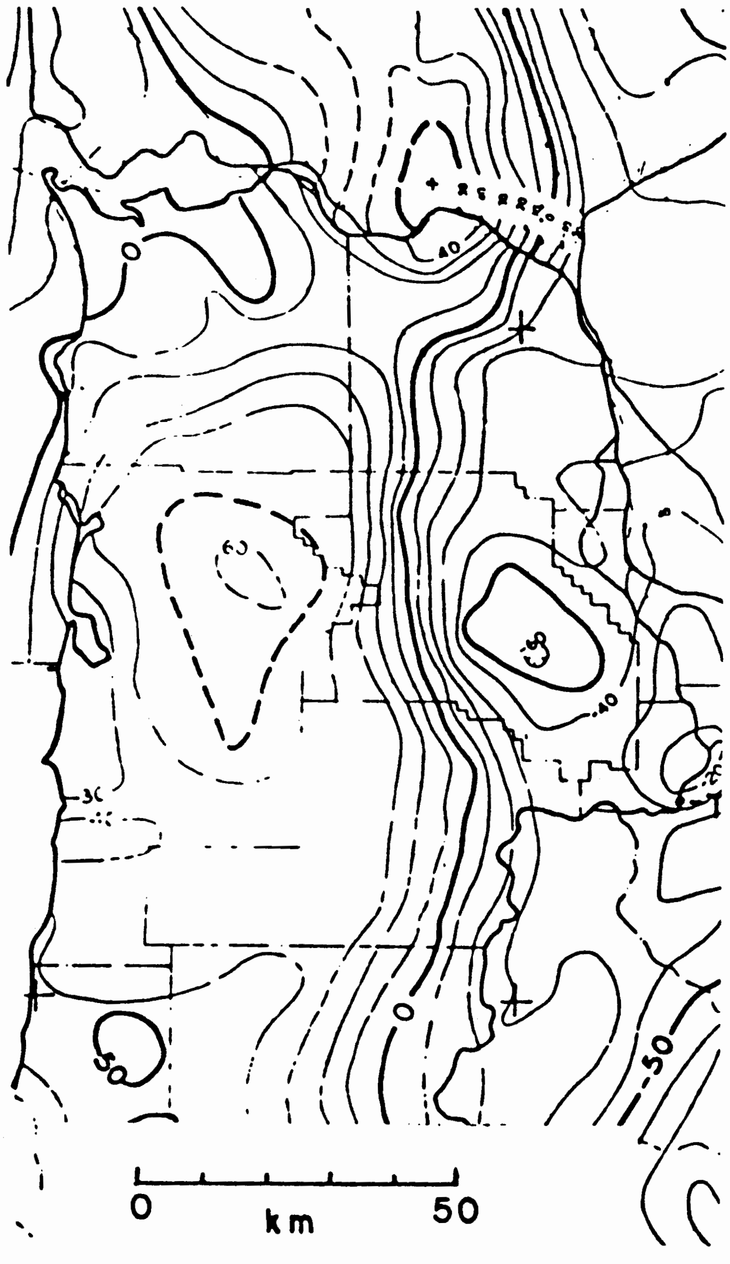


Figure 19. Bouguer gravity anomaly of northwestern Oregon and southwestern Washington (from Berg and Thiruvathukal, 1967; and Bonini and others, 1974).

controlled by the Columbia River synclinal trough. However, it is not a simple synclinal trough as the Eocene Cowlitz Formation and Goble Volcanics are overlain by the middle Miocene Columbia River basalt, and the intervening strata are missing.

Pi and Beta Diagrams and Structural Trends

Structure in the Mist area is subtle and complicated. Bedding dips are generally low ranging up to 10 or 15 degrees. Dips greater than 20 degrees are rare and probably fault controlled. A cursory examination of strikes and dips (Plate I) indicates that they change abruptly and do not clearly define folds. The regional dip is northerly in the area. There is no persistent dip direction in the subsurface as indicated by the dipmeter logs.

The outcrop pattern of the Tertiary formations and the bedding attitudes define the eastern flank and north-northeasterly plunge of the Tillamook arch. However, such a harmony does not exist in defining secondary folding or fold axes. Therefore, pi and beta diagrams were utilized in the analysis of structure. Bedding attitudes from the geologic map of T. 4, 5, 6 and 7 N., R. 4 and 5 W. (Kadri and others, 1981), were incorporated along with the bedding attitudes from the thesis area.

The Keasey Formation, siltstone and laminated members of the Pittsburg Bluff Formation, and the Scappoose Formation are used as structural domains, and the bedding attitudes of these formations were used in generating pi and beta diagrams. Only a few bedding attitudes for the Astoria Formation were available, therefore, the pi and beta diagrams were not constructed. The pi and beta diagrams help to show the pattern of attitudes, the geometry of structure, and possibly the sequence of tectonic events.

The Pi-$S_{\bullet}$ diagrams were constructed on an equal area net from the projection of poles perpendicular to bedding. The computer generated diagrams were later reduced to a usable scale and hand contoured. Figures 20 to 23 includes Pi-$S_{\bullet}$ diagrams of the Keasey Formation, the siltstone and laminated members of the Pittsburg Bluff Formation, and the Scappoose Formation. Each of the Pi-$S_{\bullet}$ diagrams has a well developed point maximum situated near the center of the diagram indicating nearly horizontal preferred orientation of the bedding, thus substantiating the field evidence of low dips in the area. For the Keasey Formation the greater density of points in the southern hemisphere indicates generally northerly dips, whereas the greater density of points for the Pittsburg Bluff and Scappoose Formations occur in the southwestern quadrant indicating generally northeasterly dips. In Figure 24, the highest contours of the Keasey and the Pittsburg Bluff Formation

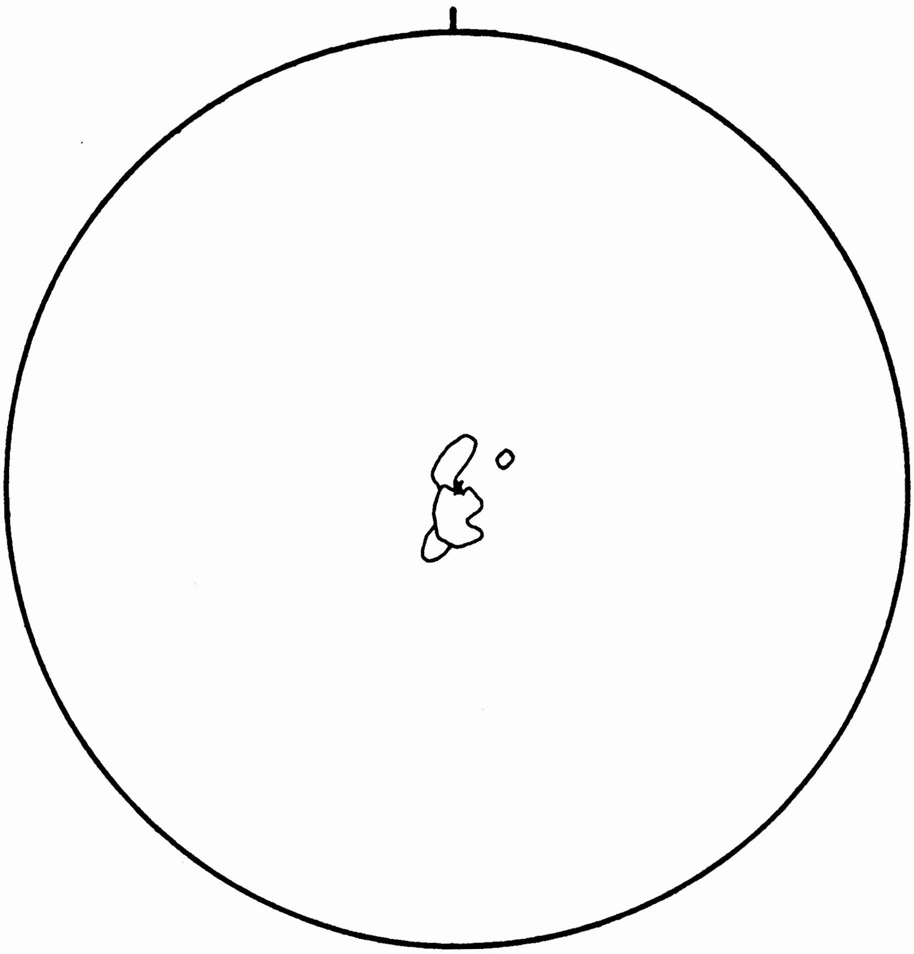


Figure 20. Contoured Pi-S_0 diagram of bedding planes from the Keasey Formation; contours at 3 and 35 percent or greater per one percent area, 27 planes.

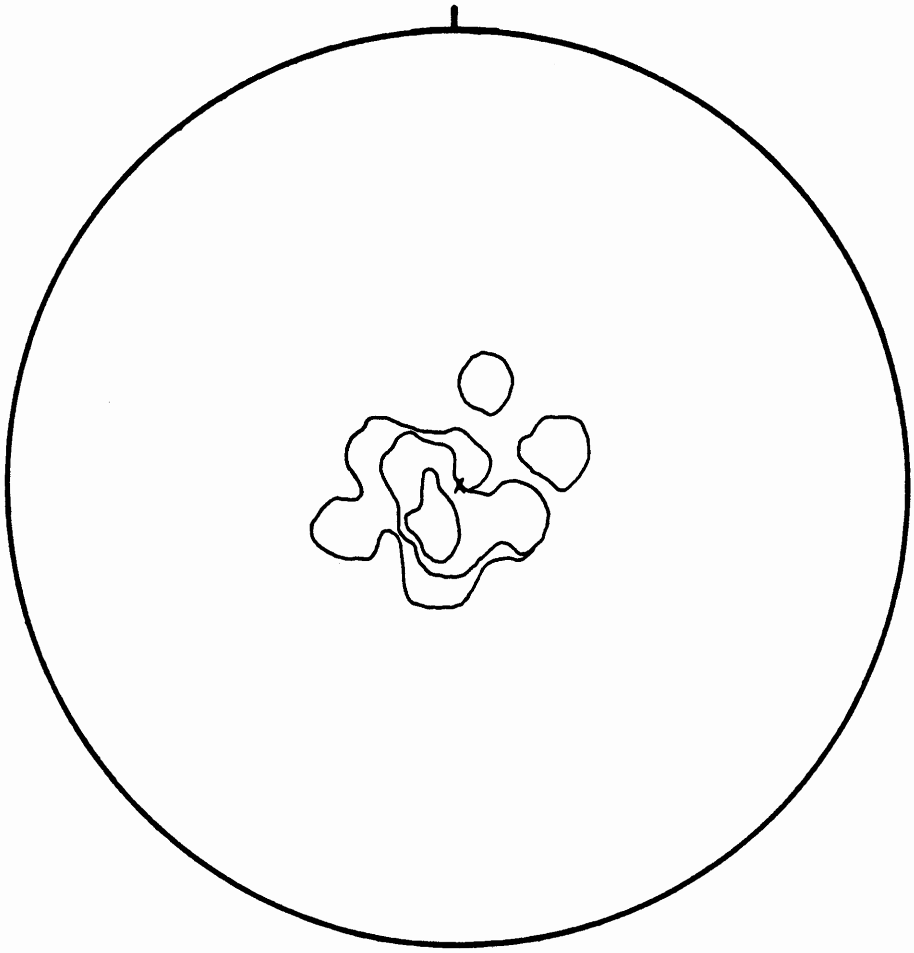


Figure 21. Contoured Pi-S diagram of bedding planes from laminated member of the Pittsburg Bluff Formation; contours at 8, 16 and 23 percent per one percent area, 15 planes.

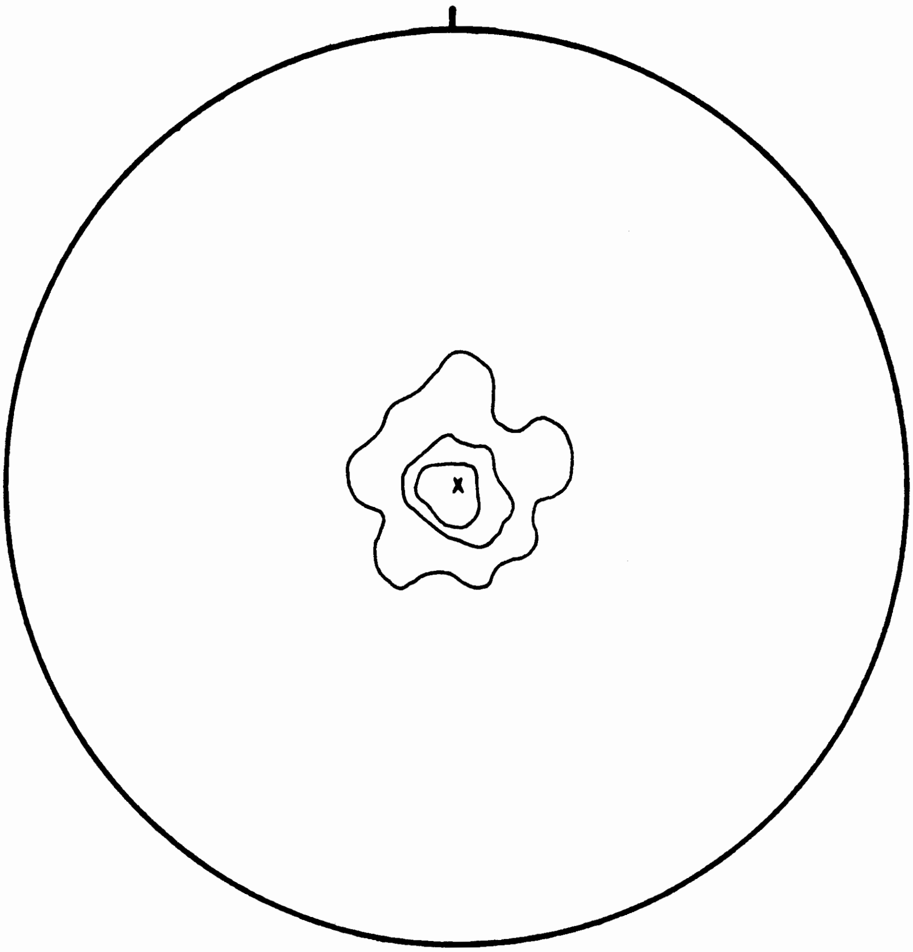


Figure 22. Contoured Pi-S_0 diagram of bedding planes from the siltstone member of the Pittsburg Bluff Formation; contours at 4, 14 and 35 percent or greater per one percent area, 42 planes.

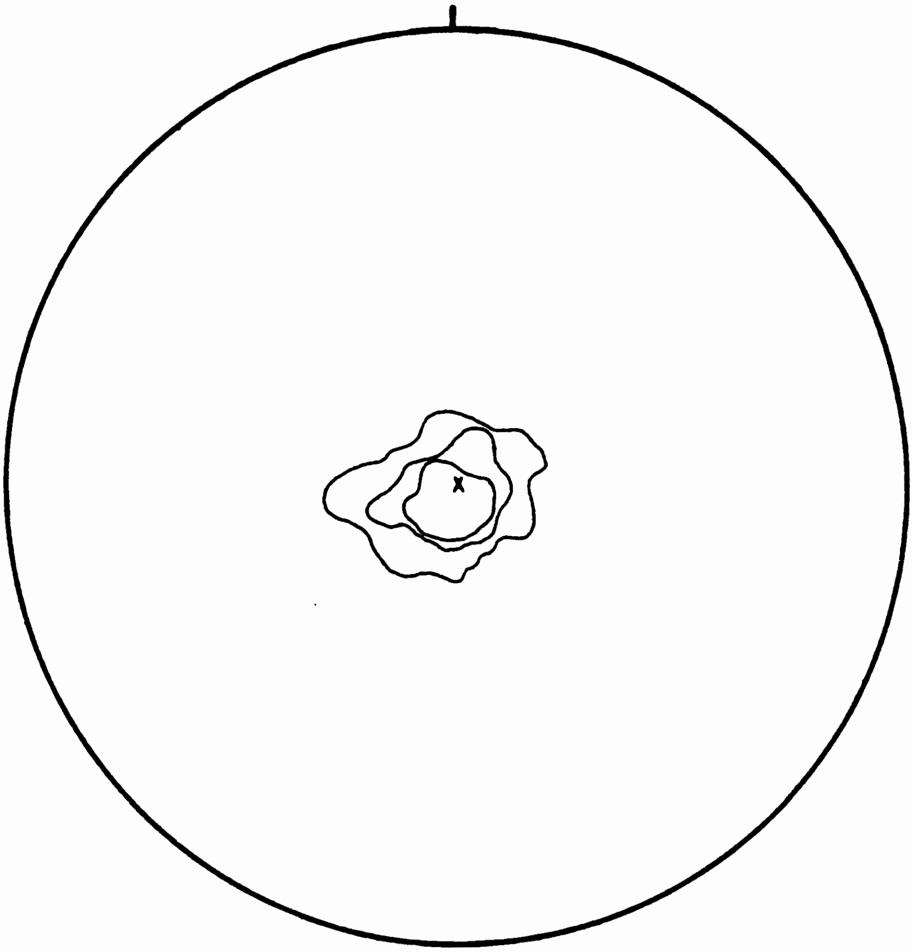


Figure 23. Contoured Pi-S_0 diagram of bedding planes from the Scappoose Formation; contours at 4, 14 and 23 percent per one percent area, 21 planes.

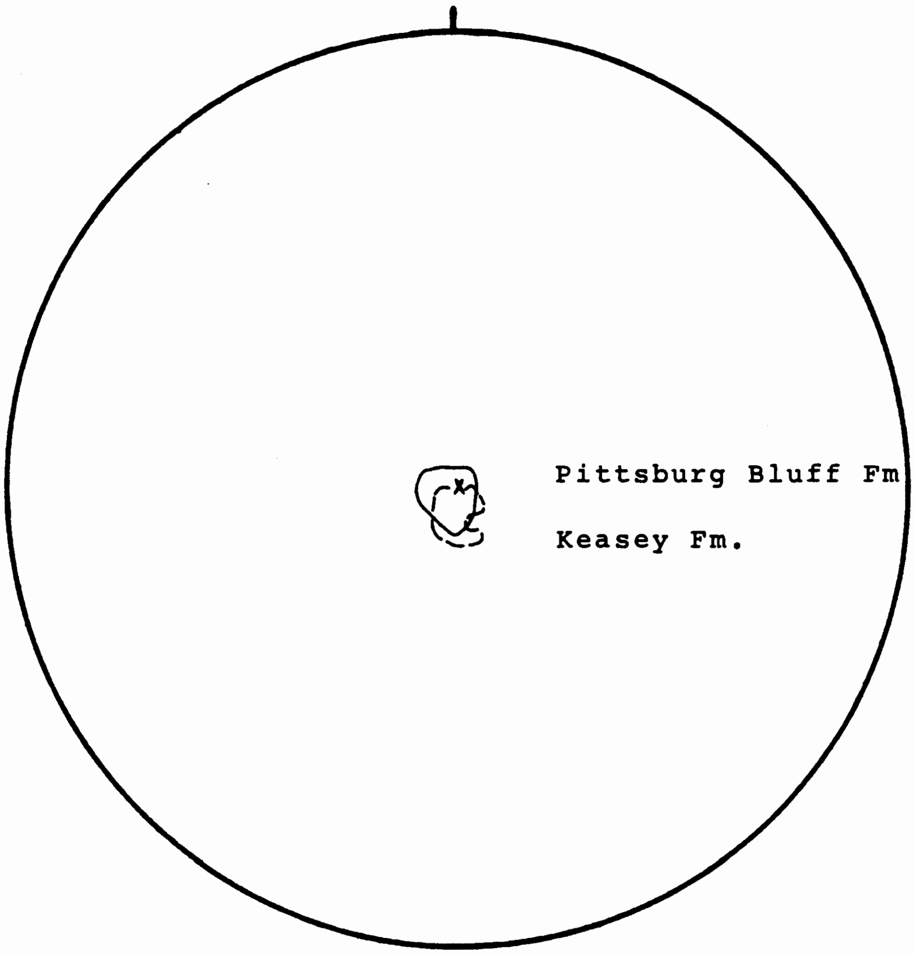


Figure 24. Superimposed maximum contour of the Keasey and Pittsburg Bluff Formations.

(siltstone member) are superimposed and the westward swing in the strike of the Pittsburg Bluff Formation is apparent.

Beta diagrams are contoured plots of intersections of planes on an equal area net (Figures 25 to 28). The data are the same for the Pi-S_0 diagrams. In the beta diagrams, the number of intersections possible is given by the formula: n x (n-1)/2, where n is the number of planes. Therefore, for 27 bedding attitudes of the Keasey Formation, n=27 and 27 x 26/2 = 351 points. The program BETACAL, developed by G. T. Benson and C. F. Gullixon for use with a Honeywell 66/20 computer, was utilized to generate the densities of points which were later hand contoured.

Figure 25 is a beta diagram for the Keasey Formation which shows near horizontal Beta-axes distributed in a variety of directions. However, the greater concentration of points of intersections occur in the interval 250° to 318°, and the highest contour defines a horizontal Beta-axis trending approximately 274°.

The beta diagram of the laminated member of the Pittsburg Bluff Formation (Figure 26) again shows near horizontal Beta-axes in all directions. The diagram fails to suggest any preferred Beta-axis. Along with the Pi-S_0 diagram, the beta diagram of the laminated member is slightly different than the diagram of the rest of the

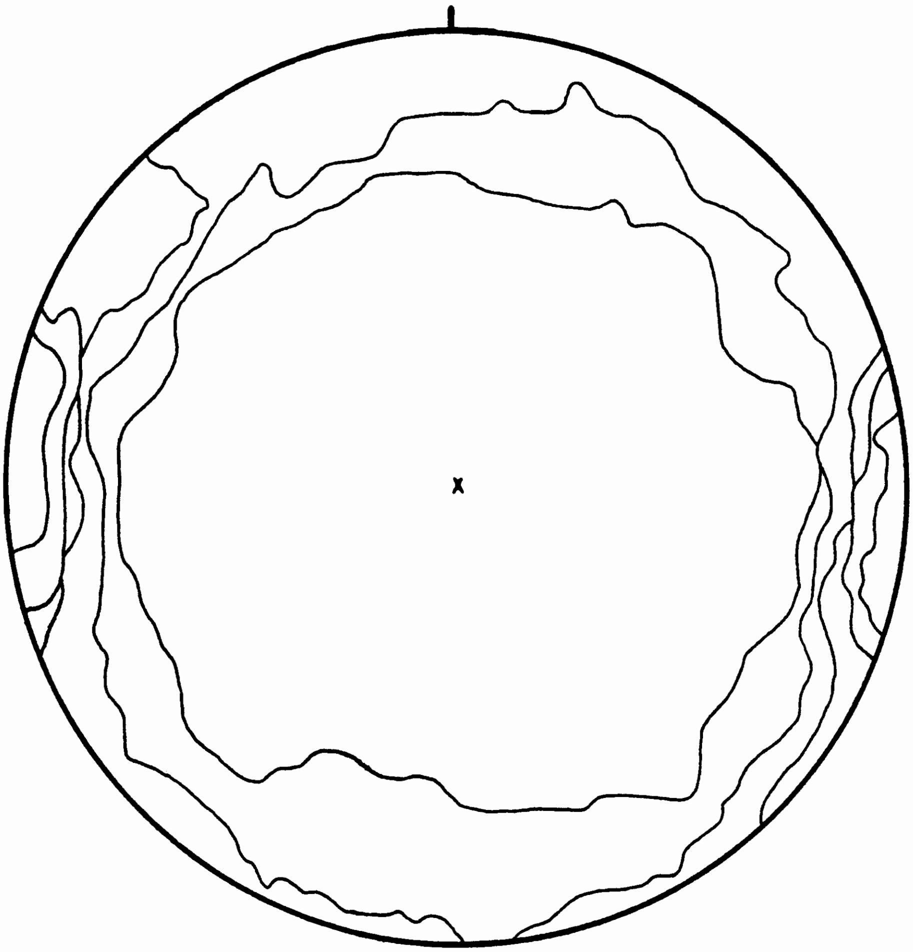


Figure 25. Contoured beta intersection diagram of bedding planes in the Keasey Formation; contours at ½, 4, 9, 13 and 16 percent per one percent area, 351 points.

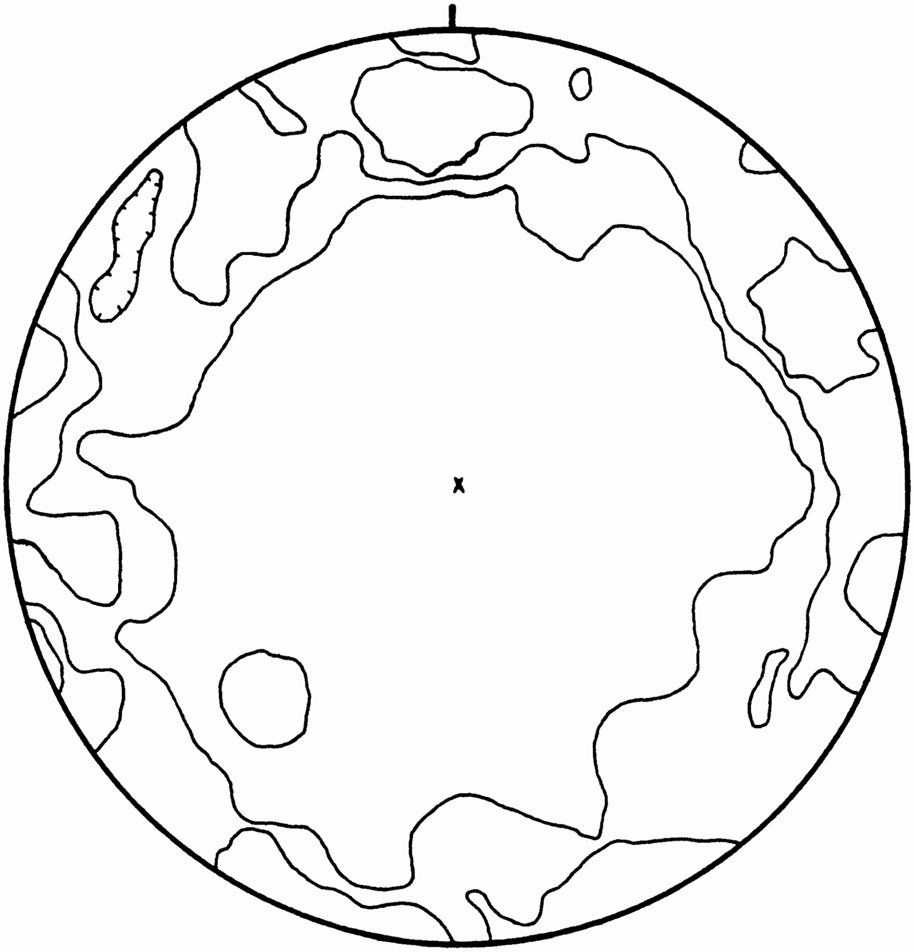


Figure 26. Contoured beta intersection diagram of bedding planes in laminated member of the Pittsburg Bluff Formation; contours at ½, 3 and 7 percent per one percent area, 105 points.

domains. The Pi-S_0 maximum of the laminated domain is not as accentuated as the rest of the domains, and the maxima of the Beta-axes are not symmetrically compensated in both the hemispheres as is the case in the rest of the beta diagrams. The reason for this inconsistency is not clearly understood; perhaps penecontemporaneous slumping may be the cause.

Figure 27 is a beta diagram of the siltstone member of the Pittsburg Bluff Formation. Once again, the diagram reveals near horizontal Beta-axes distribution in all possible directions but it also defines a relatively well developed Beta-axis trending 24 degrees. The northeast-trending Beta-axis may indicate the development of a new structural trend during Pittsburg Bluff time (Oligocene). Oligocene was the time of uplift in the Coast Range (Snavely and others, 1980), and northeast-trending Beta-axis coincides with the axis of the Tillamook arch. However, most of the outcrop area of the Pittsburg Bluff Formation (siltstone member) lies on the eastern flank of the Tillamook arch, therefore, the majority of the bedding attitudes came from the eastern flank. Therefore, it is unlikely that the Tillamook arch is solely responsible for generating the northeast-trending Beta-axis. A Beta-axis is not necessarily an axis of folding; <u>faulting</u> could also affect attitudes to generate a Beta-axis (Turner and Weiss, 1962). Generation of a Beta-axis by faulting requires

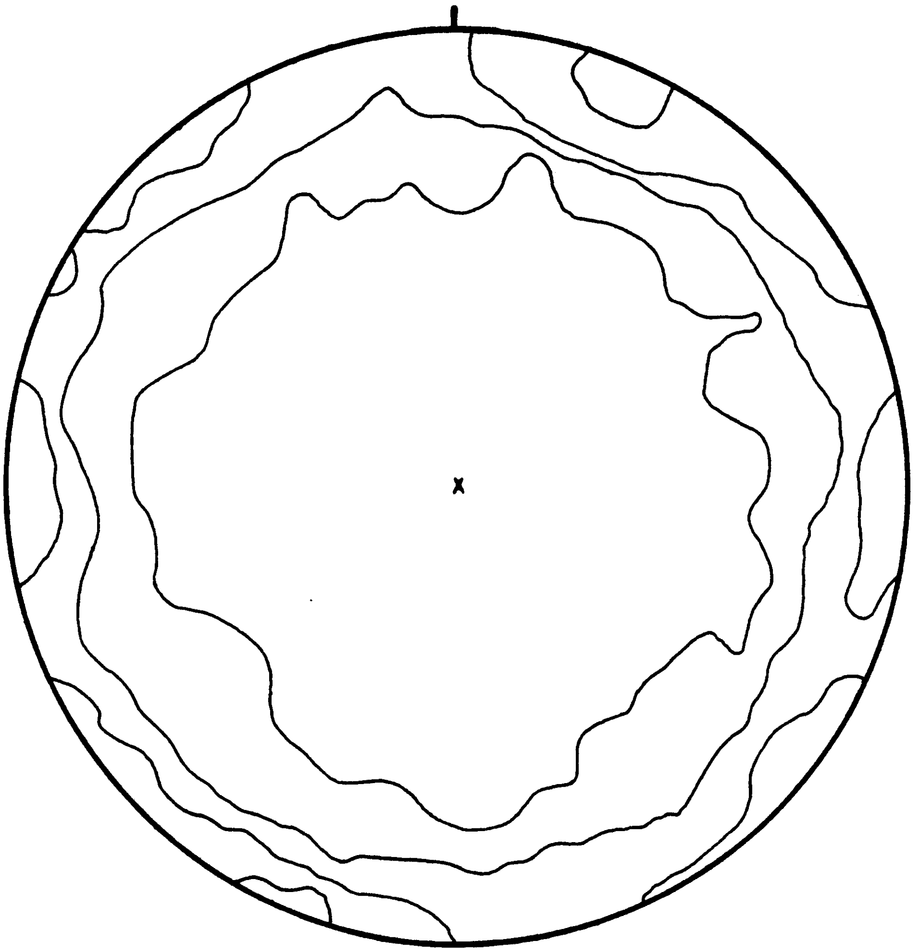


Figure 27. Contoured beta intersection diagram of bedding planes in siltstone member of the Pittsburg Bluff Formation; contours at ½, 3, 7 and 14 percent per one percent area, 861 points.

modification of bedding attitudes that would generate a majority of intersections of planes in the orientation of the fault or fault zone. Faulting usually modifies the bedding orientation on either side of the fault plane, and if a slightly opposing sense of attitude results, it would generate a Beta-axis paralleling a fault or fault zone. Therefore, the northeast-trending Beta-axis is not necessarily an axis of folding but it may well indicate a structural trend in that direction.

The Scappoose Formation beta diagram (Figure 28) shows two well defined Beta-axes at 11° and 317°. The 317° trending axis represents the latest structural trend in the area. Regionally, the northwest trend is also the youngest structural trend. Along these northwest-trending structures, vertical movement appears to have been significant. Flows of the middle Miocene Columbia River basalt in northwestern Oregon appear to be generally confined to, and are thicker in, northwest-trending linear depressions (Beeson, personal communication, 1982). Therefore, the northwest-trending structures appears to have been active during middle Miocene. However, since the Scappoose Formation also has a well developed northwest-trending Beta-axis, the structure may have begun developing in even earlier time.

The north-northeast trending Beta-axis is also well developed in the beta diagram of the Scappoose Formation.

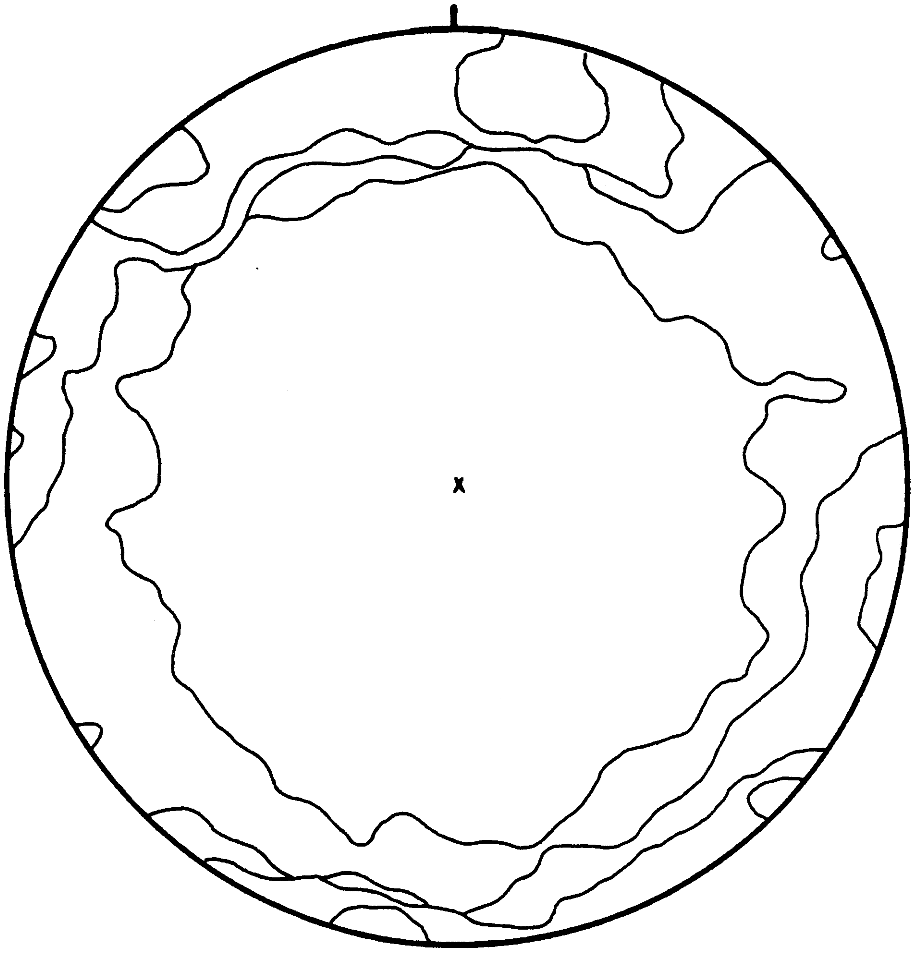


Figure 28. Contoured beta intersection diagram of bedding planes in the Scappoose Formation; contours at ½, 3, 7 and 14 percent per one percent area, 210 points.

Since the Pittsburg Bluff Formation also has a well developed north-northeast trending Beta-axis, presumably the development of north-northeast trending structure continued through Scappoose time.

Analysis of bedding attitudes utilizing an equal area net has been most helpful in determining important structural trends. The Pi-S_0 diagram of the formations show near horizontal pattern of preferred orientation of the bedding. Generally northerly dips of the Keasey Formation, and northeasterly dips of the Pittsburg Bluff and Scappoose Formations suggest an unconformable relationship between the Keasey and the Pittsburg Bluff Formations. All the beta diagrams show considerable scatter around well defined Beta-axes. The scattering of lines of intersections around a defined Beta-axis, according to Turner and Weiss (1963) represents "deviation from strictly cylindrical folding plus error in field measurments". Error in the field measurement may be a factor, however, it is probably minimal. As the scattering of lines of intersections around a defined Beta-axis due to measurement error or deviation from strictly cylindrical folding, the fold axis would more likely have some degree of plunge associated with it. As stated earlier, faulting or more correctly minor folding associated with faulting could also generate a Beta-axis. Therefore, it may be that the defined Beta-axes of the three formations do not unambiguously delineate fold axes, but rather imply structural trends in those directions. The structural trends may indicate the trend of a fold, a fault or shear zone, and resulting secondary structures (i.e. drag). The younger northeast and northwest-trending Beta-axes of the Pittsburg Bluff and Scappoose Formations probably are not reflected in the Keasey Formation because of incompetence of the Keasey mudstones. Less well developed east-west trending Beta-axes of the Pittsburg Bluff and Scappoose Formations perhaps indicate re-activation of earlier structures. The northeast-trending Beta-axis of the Pittsburg Bluff Formation is probably associated with the tectonism involved in uplift of the Coast Range paralleling the axis of the Tillamook uplift. The northwest-trending Beta-axis of the Scappoose Formation presumably represents the latest structural trend along which vertical movement appears to be more prevalent. Regionally, the northwest trend is also the youngest trend.

Faults

Faults are difficult to discern due to lack of recognizable marker beds in the formations, deep weathering, and limited outcrops. Figure 29 is the map of faults in the area indicated by field mapping, and the pattern is apparent. The dominant fault trend as expressed at the surface appear to be first, northwest-southeast and second,

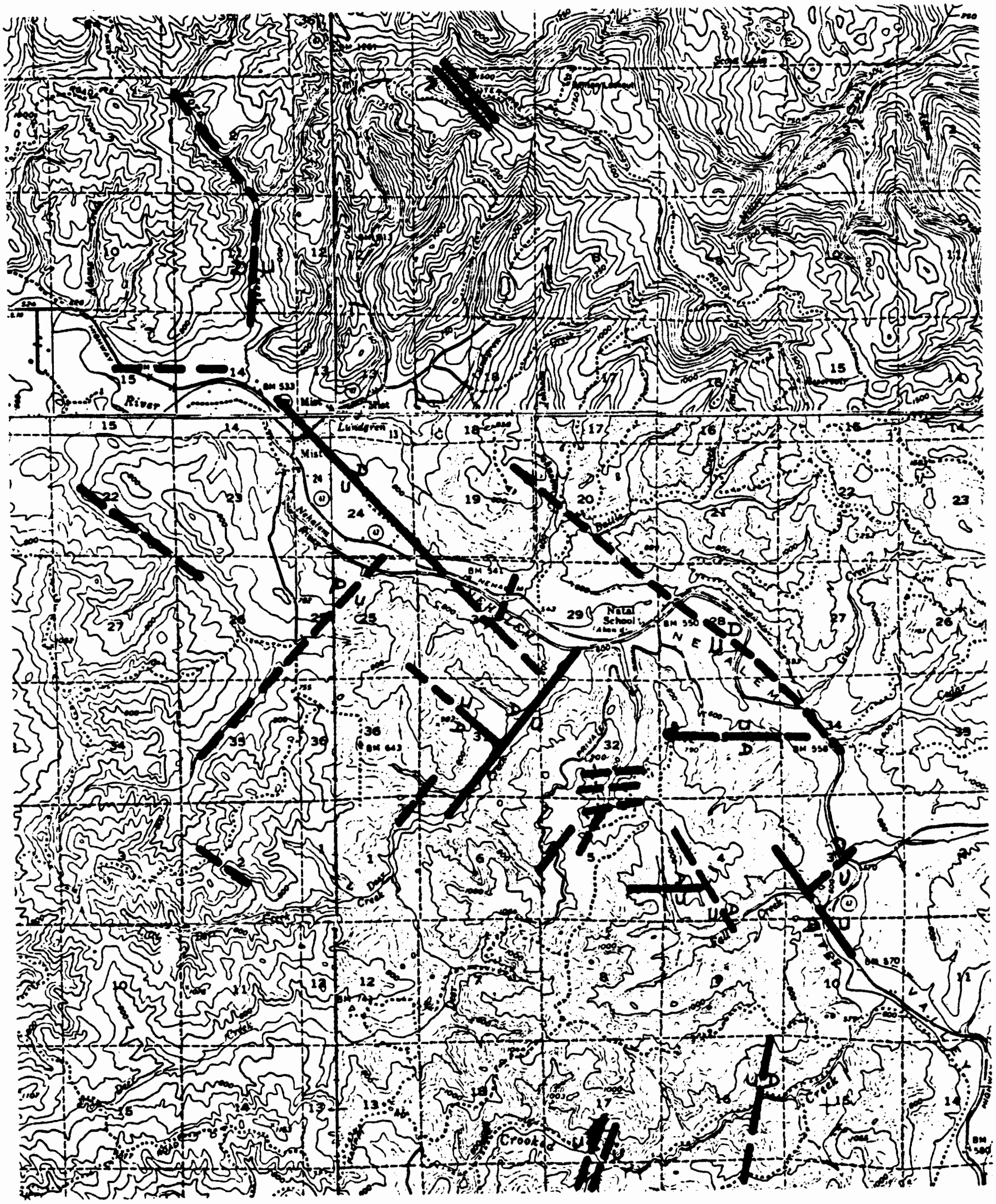


Figure 29. Map of faults in the area; long-dashed lines are approximately located faults, and short-dashed lines are inferred faults.

northeast-southwest; slightly less obvious is an east-west trend.

Some of the indicated faults juxtapose different stratigraphic units and hence are labelled 'Approximately Located', and shown as long-dashed lines on the Geologic Map (Plate I), and Figure 29. Solid lines represents exposed or definite faults, while short-dashed lines indicate inferred faults. The indicated inferred faults are drawn because of opposing sets of strikes and dips in the stratigraphic unit or a strong and persistent lineament.

The siltstone member of the Pittsburg Bluff Formation has a concentration of fractures and joints north of Mist, whereas such a density is not apparent south of Mist. Fractures and joints observed in the Keasey Formation are seldom linear or straight, but are generally curved. While some of these stop abruptly, some continue en-echlon. In contrast to the Pittsburg Bluff and Keasey Formation, fractures and joints are not as apparent in the poorly consolidated sediments of the Astoria Formation.

The majority of exposed and probably small faults along the Clatskanie Tie road in NW/4 section 6, T. 6 N., R. 4 W., trend N. 50 to 55 W., but a few trend N. 35 E. Among these faults, fault 'A' (Figure 30) which trends 50/69 NE is probably the largest among the exposed faults. This fault may have more than 35 meters of dip-slip

Figure 30. Two larger, exposed faults along the Clatskanie Tie road; in the middle, light-colored, cross-bedded, coarse sandstone of the Astoria Formation is juxtaposed by a northeast dipping fault with basalt derived colluvium to the left, and with Grande Ronde flows by a southwest dipping fault to the right.

displacement. No slickensides are apparent. The clayey fault zone is about 1 cm wide and juxtaposes cross-bedded sandstone of the Astoria Formation on the upthrown side, and basalt derived colluvium on the downthrown side.

Faults exposed along the Clatskanie Tie road have steep dips, very narrow shear zones, very little if any drag and form horsts and grabens; all the necessary criteria to classify them as normal faults formed under extensional conditions. These faults are post-middle Miocene since they cut Columbia River basalt and associated sediments.

On the northwest-trending ridge in section 25, T. 6 N., R. 5 W., and section 30, T. 6 N., R. 4 W., neither the laminated nor the siltstone members of the Pittsburg Bluff Formations overlie the Keasey Formation (Plate I). A major northwest-trending fault(s) has relatively upthrown this northwest-trending ridge and down-dropped the north side probably more than 150 meters. Further indication of this fault comes from a sharp break in lithology along the Nehalem River in section 30, T. 6 N., R. 4 W., between highly <u>Helminthoidea</u> burrowed mudstone on the upthrown side and silt mottled mudstone on the downthrown side. This fault appears to pre-date middle Miocene because a poorly consolidated sandstone containing mud and weathered basalt pebbles of the Astoria Formation crops out on the northwest-trending ridge in section 25, T. 6 N.,

R. 5 W., at relatively the same topographic elevation as north of Mist in sections 11 and 12, T. 6 N., R. 5 W.

The majority of faults in the area appear to be high angle faults. The combination of low dips and high angle faults probably indicates a complex form of block faulting. The orientation of block faulting is generally controlled by the stresses and pre-existing structure (Hobbs, 1976). If the block faulting is basement controlled, then the basement pattern of deformation is imparted to the overlying sedimentary strata as seen in Grand Canyon and Wyoming area (Hodgeson, 1961). Basin and Range block faulting, as implied by Shaw (1965) and Albers (1967), is controlled by deep seated dextral-slip movement. The basin and Range province, along with the Oregon Coast Range, have a thin crust.

The fundamental tectonic framework of the western North America is governed by differential motion between the North American and Pacific plates. This differential motion has produced a broad belt of dextral-slip movement. Within this belt lies the San Andreas fault in California and Walker Lane fault in Nevada, and continuation of this trend in Oregon along the Brothers Fault zone and the Eugene-Denino lineament are the prominent features. In the Coast Range of the northwestern Oregon, the Portland Hills and Gales Creek fault probably represents the continuation of the northwest-trending linear zones. However, the northwest-trending structures in northwestern Oregon may have significant associated vertical movement.

Lineaments

Topographic maps, high altitude black and white, and infra-red aerial photographs together with side looking radar imagery (SLAR) were examined for lineaments. However, the lineaments were drawn (Figure 31) from SLAR as it enhances the geologic structure in vegetated terrains (Sabins, 1978; p. 207). The slanted microwave beam of the SLAR system produces a shadow which exaggerates surface-expressed geologic features. Fractures are more readily delineated because of this shadow effect (Wing, 1971). Linear features on the radar imagery are generally indicative of faulting, and fault interpretation is classified in two catagories: (1) persistent linears and (2) offsetting linear patterns (McDonald, 1969). Almost all the lineaments in the study area are persistent linears.

The east-west flight path and south look direction of the radar imagery (flown by Westinghouse Electric Corporation, 1973; for Washington Power Supply System) has differentially highlighted the east-west trending geologic features. The parallelism among the northwest and north-east-trending sets of lineaments is striking. Apart from a few lineaments, the majority of the lineaments are only

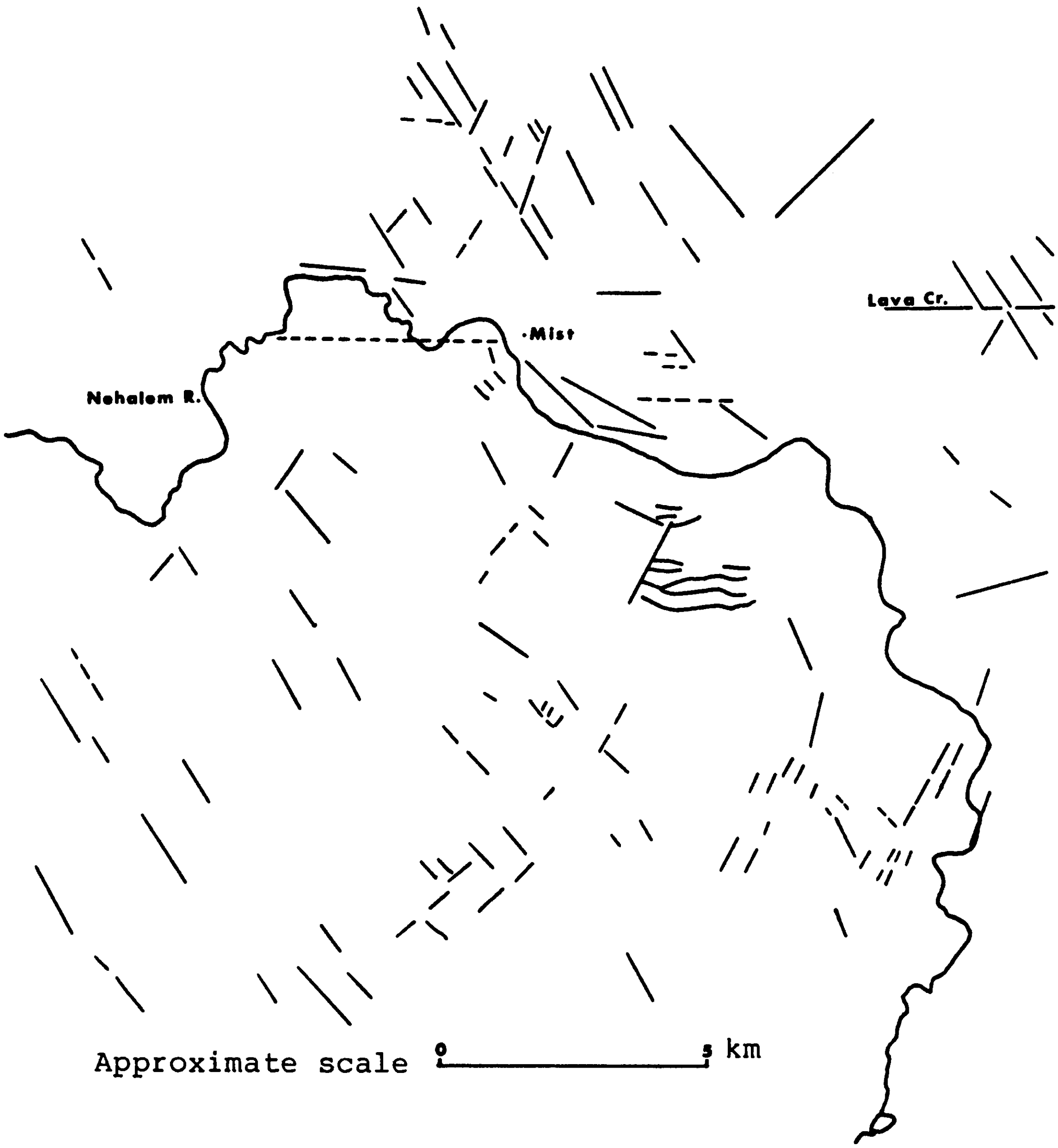


Figure 31. Map of lineaments drawn from SLAR.

a few hundred meters long.

An en-echelon zone of northwest-trending lineaments appears to pass through the northeastern corner of the study area. Faults exposed along the Clatskanie Tie road appear as lineaments on the radar imagery. Some of the northwest-trending lineaments appear to be truncated along the strike of an east-west trending Lava Creek lineament. An en-echelon zone of northeast-trending lineaments passes through the southeastern corner of the study area, north of Pittsburg. These northeast-trending, slightly curved lineaments can be traced northward to the Columbia River, and south to the periphery of the Tillamook highlands. The significance of anomalous arcuate lineaments southeast of Mist is not understood at present.

The SLAR imagery appears to only slightly differentiate the sedimentary units. Generally, the tone of the area underlain by the Keasey Formation is light gray compared to the dark gray tone of the laminated member of the Pittsburg Bluff Formation. An incised texture appears to delineate the area underlain by the siltstone member of the Pittsburg Bluff Formation from the Keasey Formation and laminated member of the Pittsburg Bluff Formation which have diffused hummocky texture.

The analysis of the radar imagery is interpretative and used as a supplement to the field data. The majority of lineaments reflect drainage. The parallelism among the northwest and northeast sets of lineaments, the lack of continuity of individual persistent linears but continuation of some of the linears en-echelon is in unison with the field observation for the fractures and faults in the area. Therefore, the lineaments are perhaps indicative of the structural grain of the region.

Unconformities

The Keasey Formation appears to be unconformably overlain by the Pittsburg Bluff Formation. A sharp lithologic and megafaunal break occurs between the Keasey and Pittsburg Bluff Formations (Moore, 1976). The contact between the Keasey and Pittsburg Bluff Formation is partially exposed in the bluff along the Nehalem River in sections 28 and 33, T. 6 N., R. 4 W. Fine grained, bioturbated sandstone containing thin coal lenses are underlain by silty mudstone. The contact between the sandstone and silty mudstone is marked by a thin (4-7 cm) pebbly conglomerate layer. Down section along the bluff, a concretionary layer in the tuffaceous mudstone of the Keasey Formation permits the measurement of the bedding attitude, and the average of several attitudes reveal a slightly steeper dip than the dip of the Pittsburg Bluff Formation upsection (Plate I). The diagnostic assemblage of *Uvigerina cocoaenesis* zone indicates Refugian age and outer neritic to bathyal depth of deposition for the Keasey Formation. Thin coal lenses in the bioturbated sandstone of the Pittsburg Bluff Formation perhaps represents a near shore, shallow water deposition. This drastic change in the depositional environments perhaps marks the unconformity resulting from a regional uplift of the Oregon Coast Range. The lithologic contact between the laminated member of the Pittsburg Bluff Formation and the Keasey Formation is not exposed.

The Astoria Formation also overlies the Keasey Formation. The lithologic contact is exposed at two places. In NE/4 section 25, T. 6 N., R. 5 W., <u>Helminthoidea</u> burrowed, dark gray mudstone of the Keasey Formation is overlain by lithic arkosic to quartzose, fine grained sandstone containing mud pebbles and pebble lenses of the Astoria Formation. The bedding attitude in the unweathered part of the Keasey Formation reveals south-easterly dips, while the pebble lenses appear to have a northwesterly dip (Plate I). The sharp contact between poorly consolidated sediments of the Astoria Formation and the Keasey Formation is exposed in a road-cut in the center of section 2, T. 5 N., R. 5 W. The mudstone and siltstone of the Keasey Formation are overlain by micro cross-laminated and trough cross-bedded fine grained sandstone of the Astoria Formation. The troughs of the larger channels are lined by mud rip-ups.

Shelf type of sedimentation took place (Figure 32) following the uplift of the Oregon Coast Range, and pre-Oligocene rocks formed paleotopographic highs on the Oregon shelf (Snavely and others, 1975). The unconformity resulting from the uplift of the Coast Range appears to have initiated the deltaic sedimentation of the Pittsburg Bluff Formation.

In the Crooked Creek area, the siltstone member of the Pittsburg Bluff Formation appears to thin westward, and it is not present west of the boundary between R. 4 and 5 W. To the west of here, the Keasey Formation is in direct contact with either the laminated member or the Astoria Formation. The thinning of the siltstone member westward is further indicated by the presence of the CRBG in section 6, T. 5 N., R. 4 W. Only about 20 meters of the Pittsburg Bluff Formation separates the Keasey Formation from the CRBG at this locality. Therefore, it is apparent that only a thin wedge of the Pittsburg Bluff Formation existed prior to the deposition of the CRBG. It is unlikely that the Pittsburg Bluff Formation was almost entirely eroded away (prior to the deposition of the CRBG and the Astoria Formation) from the flank of the Tillamook arch, because the Pittsburg Bluff Formation and the CRBG are both present and thicker to the east of the Nehalem River and even to the north of Mist (on the nose of the Tillamook arch). Wedging out of the siltstone member west

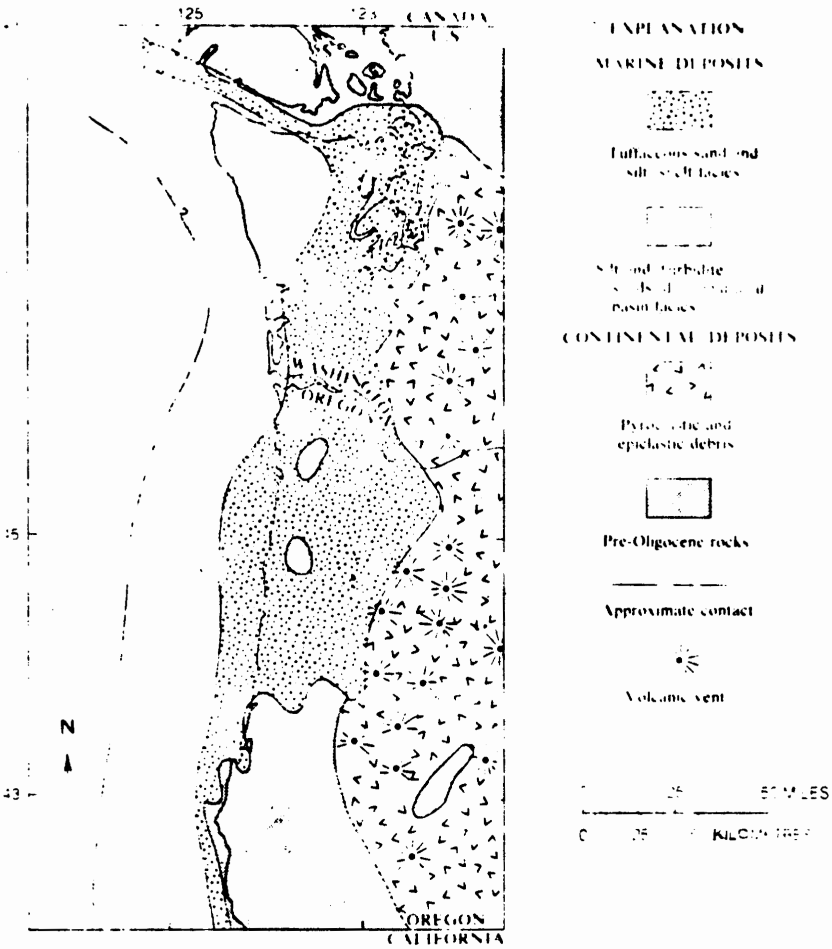


Figure 32. Distribution of shelf type of lithofacies during Oligocene (from Snavely and others, 1975).

and southward inside the Nehalem River loop is perhaps depositionally controlled. Figure 33 illustrates probable stratigraphic relationships between the Keasey Formation and the laminated and siltstone members of the Pittsburg Bluff Formation. As observed in the field, the figure indicates direct contact between the siltstone member and the Keasey Formation in the Crooked Creek area and thereabouts. However, to the west, as in section 2, T. 5 N., R. 5 W., the laminated member is in direct contact with the Keasey Formation. It is also apparent from the figure that, for the thinning of the siltstone member westward, there appears to be corresponding thickening of the laminated member. The Keasey Formation is in direct contact with both the members of the Pittsburg Bluff Formation, and the Astoria Formation; and the siltstone member thins westward. To explain these observations (Figure 33), a structural high may have developed on the Oregon shelf from the uplift in the Coast Range, and this high may have restricted the deposition of the Pittsburg Bluff Formation. The restriction of the deposition of the Pittsburg Bluff Formation by the structural high may also explain the presence of only about 20 meters of the Pittsburg Bluff Formation separating the Keasey Formation and the CRBG in section 6, T. 5 N., R. 4 W.

More uplift in the Coast Range, probably during early and/or middle Miocene, is indicated by the

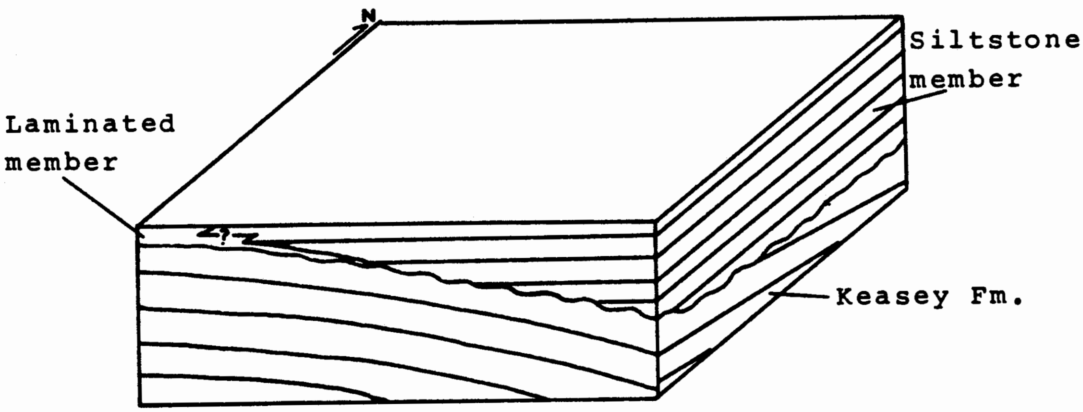


Figure 33. Diagramatic sketch illustrating probable stratigraphic relationships between the Keasey, and siltstone and laminated members of the Pittsburg Bluff Formation.

unconformable relationship between the Pittsburg Bluff Formation and the overlying strata, namely, the Astoria Formation and the CRBG. The contact between the Pittsburg Bluff and the Astoria Formation is exposed north of Mist along Oregon Highway 47. Fine grained, bioturbated, well lithified sandstone and siltstone of the Pittsburg Bluff Formation are overlain by poorly consolidated pebbly sandstone and pebble lenses of the Astoria Formation. The characteristic abundant fractures and joints are not apparent in the Astoria Formation. A similar relationship between the two formation is exposed in the Mist Gas field area, where the Pittsburg Bluff Formation is not only overlain by the poorly consolidated sediments of the Astoria Formation but also by basalt clast conglomerate. Further upsection, a thick layer of basalt clast conglomerate is overlain by pillow basalt of the Frenchman Springs Member of the Wanapum Basalt. Considerable erosion must have taken place before the deposition of the CRBG. Not only the upper part of the Pittsburg Bluff Formation, but the lower and middle members (as defined by Kelty, 1981) of the Scappoose Formation have been eroded away north of Mist. The study area lies near the axis of the Tillamook arch, therefore, the crestal part has been uplifted and eroded slightly more in comparison with the flanks. This may explain the absence of the Scappoose Formation (lower and middle members of Kelty, 1981) north of Mist. The

Astoria Formation laps onto the older units south of Mist. Figure 34 is a sketch diagram depicting the embayment that developed prior to the extrusion of the CRBG. This shallow, wide structural embayment restricted the deposition of the CRBG and the Astoria Formation within the confines of the flanking subaerial topographic highs.

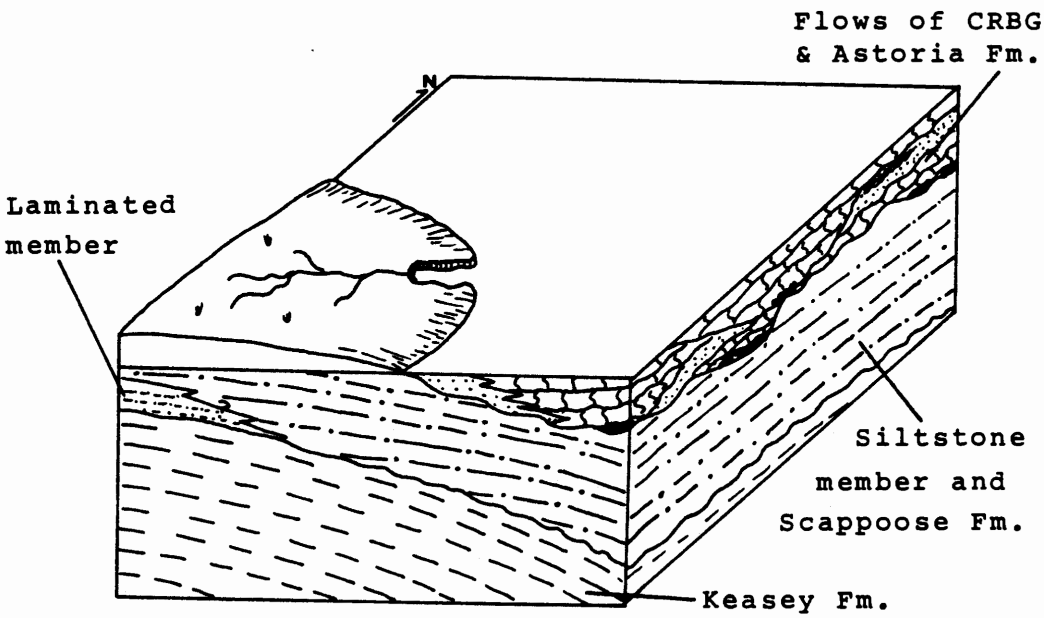
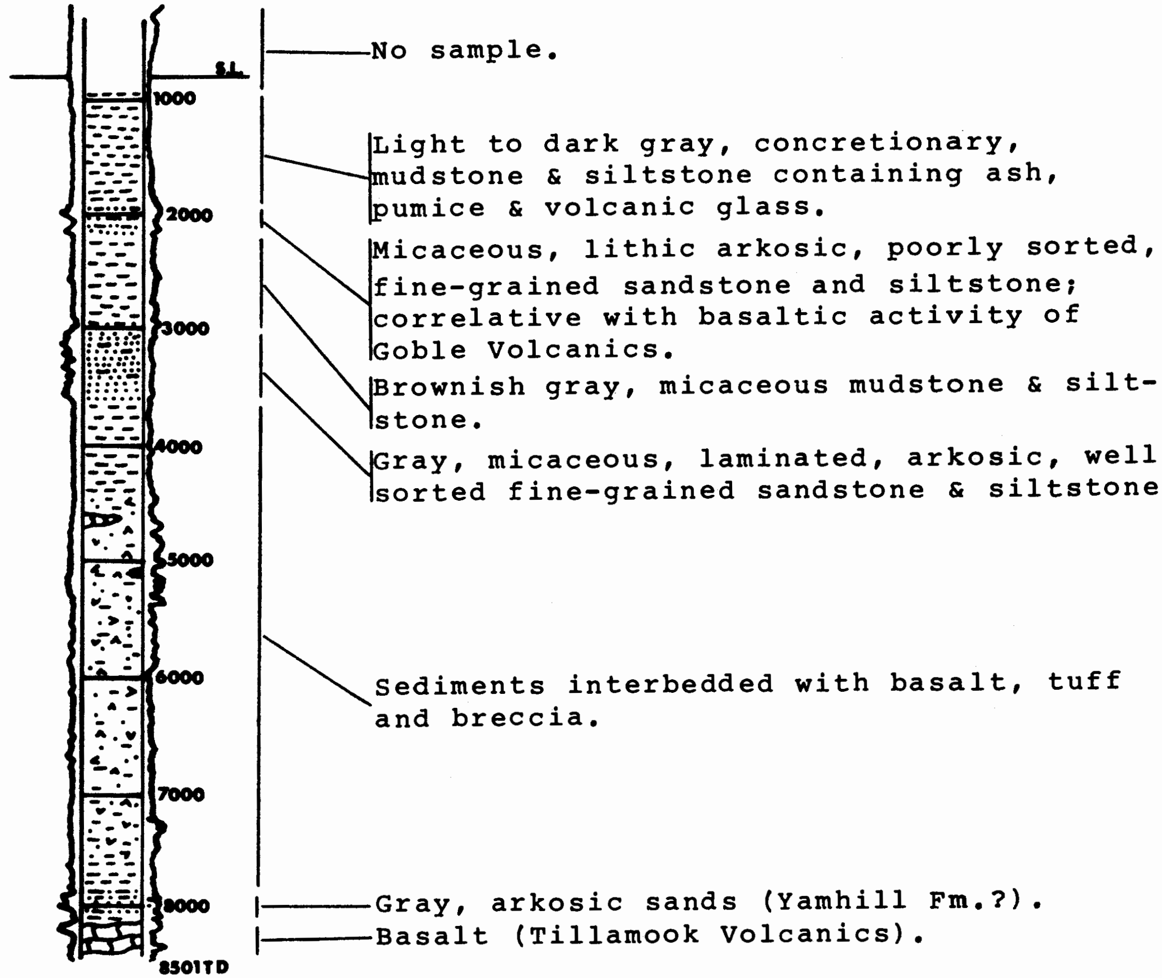


Figure 34. Sketch diagram illustrating the middle Miocene embayment that may have restricted the basalt flows and deposition of the Astoria Formation.

SUBSURFACE ANALYSIS

Cores from the Texaco "Clark and Wilson" well, and cuttings of Columbia County Nos. 1 and 2, and first re-drill of Longview Fiber No. 1 were examined. Emphasis was placed on noticing lithologic variations in the thick fine grained sections of each of these wells. Examination of the cores of the Texaco "Clark and Wilson" well (Figure 35) indicates a sedimentary section above 1900' consisting predominantly of tuffaceous, micromicaceous mudstone and siltstone containing pumice, volcanic glass and occasional Helminthoidea burrows in the mudstone. The section from approximately 1900' to 2200' consists of tuffaceous, micaceous, poorly sorted, fine grained, lithic arkosic sandstone and siltstone. Basaltic, pebbly sandstone (2034'), and higher scandium concentration in one analyzed sample (2076') indicate the influence of basaltic activity (Goble Volcanics; Bruer, personal communication, 1982). McKeel's (1979) foraminiferal evaluation of the Texaco well indicates Narizian age, and bathyal to neritic depth (samples examined were from 575' onwards). McDougal (1980) places the Cowlitz-Keasey (Narizian-Refugian) contact at approximately 1000'. Dark gray to brownish gray, micaceous mudstone predominate from about 2200' to about 3000'. Below this, light gray,



<u>Figure 35</u>. Log of Texaco "Clark and Wilson" well.

micaceous, arkosic, fine grained sandstone (Clark and Wilson sands) are invariably laminated. The laminae are either entirely composed of large muscovite and biotite flakes, and/or carbonized plant material. Some of these laminae (carbonaceous) are as much as 3 to 4 mm thick. The overall permeability of the Clark and Wilson sands varies from 80 to 1300+ millidarcies and porosity ranges from 23 to 31 percent (Newton and Van Atta, 1976). The Clark and Wilson sands are 750' thick in the Texaco well. Sediments below the Clark and Wilson sands are interbedded with tuffs, basalts and breccias. Arkosic sands at 7900' (Yamhill Formation ?) is similar in lithology to the Clark and Wilson sands. Basalt predominate below 8000'. Chemical analysis of one basalt sample from 8479' (core # 135) is plotted with the available data from the Tillamook Volcanics (Figure 14).

Rocks below 8000' in the Texaco well are brittle while above 4000' they are moderately to well indurated. There is a general increase in number of fractures with depth, and low angle fractures with horizontal slickensides are apparent. Dips greater than 15 degrees are uncommon. Dips are generally low and range from horizontal to a few degrees.

The Mist field lies about 5 kilometers west-northwest of the Texaco "Clark and Wilson" well. Typically, the wells in the Mist field have cut through a thick section of predominantely siltstone and mudstone to reach the producing Clark and Wilson sands. The section above the Clark and Wilson sands can be broadly divided into three lithologic units, correlative with the Pittsburg Bluff, Keasey and Cowlitz Formations. Primarily, relatively coarser grain size separates the Pittsburg Bluff from Keasey type lithology as seen in the cuttings of the Columbia County No. 1 (Figure 36). The cuttings of the Keasey type lithology are gray, tuffaceous, micromicaceous siltstone and mudstone, while those of the Cowlitz are brownish gray, micaceous, carbonaceous silty mudstone, laminated mudstone and claystone. Authigenic pyrite is relatively more prevalent in the Cowlitz mudrock than the Keasey; on the other hand the Keasey has a higher amount of volcanic glass shards compared to the Cowlitz Formation.

The thickness of the Keasey and Cowlitz rocks vary considerably, and to account for these variations, Bruer (1980) proposed a "Nehalem Gorge", which eroded the Cowlitz sediments and filled it with the Keasey age sediments.

A profound unconformity separates the Keasey and Cowlitz Formations (Bruer, 1980; personal communocation, 1982). Two more unconformities occur between the Keasey and Pittsburg Bluff, and between the Pittsburg Bluff and Astoria Formations.

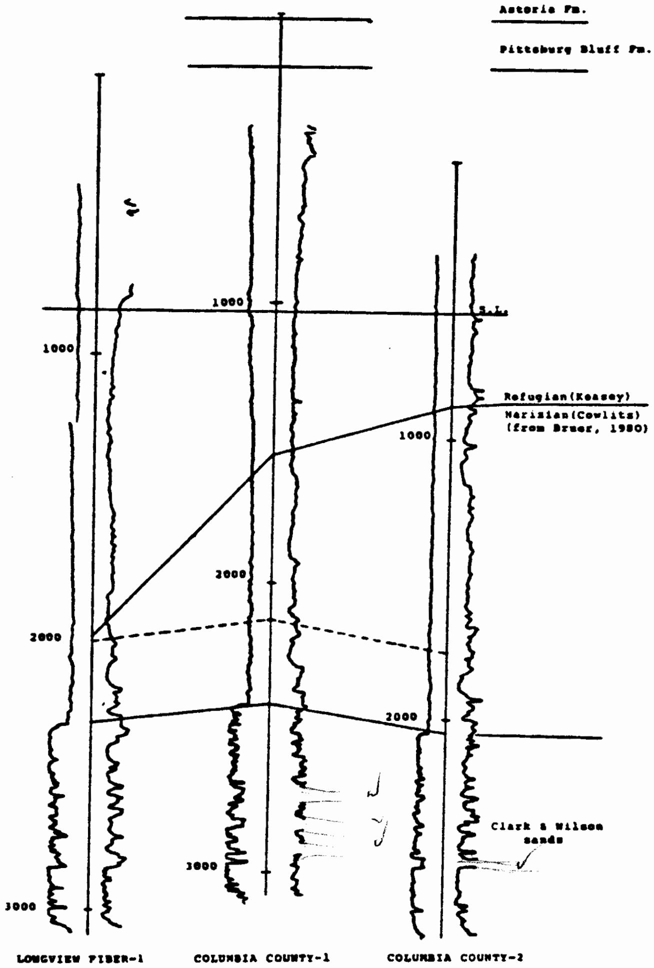


Figure 36. Subsurface stratigraphic correlations of three wells in the Mist field.

DISCUSSION AND CONCLUSION

The Keasey Formation is distinguished from the underlying Cowlitz Formation on the basis of lithology and limited geochemistry. The Keasey Formation predominantly consists of tuffaceous siltstone and mudstone, and has a lower concentration of potassium and a low lanthanum to samarium ratio. A major change in the provenance occurs between the Cowlitz and Keasey Formations. In the Cowlitz Formation, a relatively higher amount of potassium feldspar and micas (Van Atta, 1971), and a higher concentration of potassium indicate a granitic-metamorphic dominated provenance. The post-Cowlitz provenance includes volcanic component. The Keasey Formation is unconformably overlain by the deltaic deposits of the Pittsburg Bluff Formation. The siltstone member (informal) of the Pittsburg Bluff Formation crops out in an arcuate pattern (generally conforming to the outcrop pattern of the CRBG), and thins rapidly to west. The laminated member (informal) of the Pittsburg Bluff Formation increases in the thickness to the west. Although confirming field evidence is lacking, a facies relationship may exist between the siltstone and laminated members. The Pittsburg Bluff Formation is overlain to the east of the study area by the Scappoose Formation. The Scappoose Formation consists of shallow marine to brackish water, feldspathic lithofacies derived from the granitic-metamorphic terrane by ancestral Columbia River drainage system (Kelty, 1981). In the study area, the Pittsburg Bluff Formation is overlain by the Astoria Formation (upper middle Miocene member of the Scappoose Formation of Kelty, 1981). Field relationship and lithology indicate coeval deposition of the Astoria Formation and the Columbia River Basalt Group. An anomalously higher concentration of scandium in the Astoria Formation (pebbly sandstone samples) indicates the presence of the flood basalt in the provenance.

The depositional environment of the Pittsburg Bluff Formation and younger formations is relatively well understood compared to that of the Keasey Formation. Deducing the environment of deposition of the Keasey Formation from few 'quality' outcrops is further complicated by contradicting indicators (e.g. presence of pyrite together with infauna), slow and rapid rate of sedimentation, lack of correlation, and limited primary structure are among some of the salient features. Foraminiferal examination (McDougal, 1980) suggests bathyal to outer neritic depth of deposition, which implies a continental slope 'type' of deposition. This may be unlikely since, at least for one reason, the Keasey

Formation is bounded by the Cowlitz Formation which includes subaerial flows of the Goble Volcanics, and the deltaic deposits of the Pittsburg Bluff Formation. The physical parameters suggests low energy, quiet water environment of deposition below wave base. The Keasey basin may have been close to the shoreline (Moore and Vokes, 1953). The concretionary lenses with their fining upward sequence suggest rapid deposition in shallow, wide troughs or channels. Along with the concretionary lenses, the exposed wide submarine channels (with no apparent graded bedding) indicate deposition on a basin floor which had a fairly low gradient. A deeper (middle neritic ?) shelf 'type' of basin with a relief (produced by slumping, growth faults or by some other mechanism = lutokinesis) and cut by meandering(?) submarine channels would probably explain the lack of lateral correlation and indicate rapid and slow rates of sedimentation. Furthermore, the muds are distributed unevenly (Potter and others, 1980), such that they are thicker in the lows and only blanket highs. Coarse grained lithofacies in the Keasey Formation are uncommon but not absent, even though the shore-line may have been close by. Perhaps the coarser lithofacies may be confined to a certain portion of the Keasey basin. Figure 37 depicts some of the features of the Keasey basin. In summary, the depositional environment of not only the Keasey, but the Cowlitz mud rocks appear to be

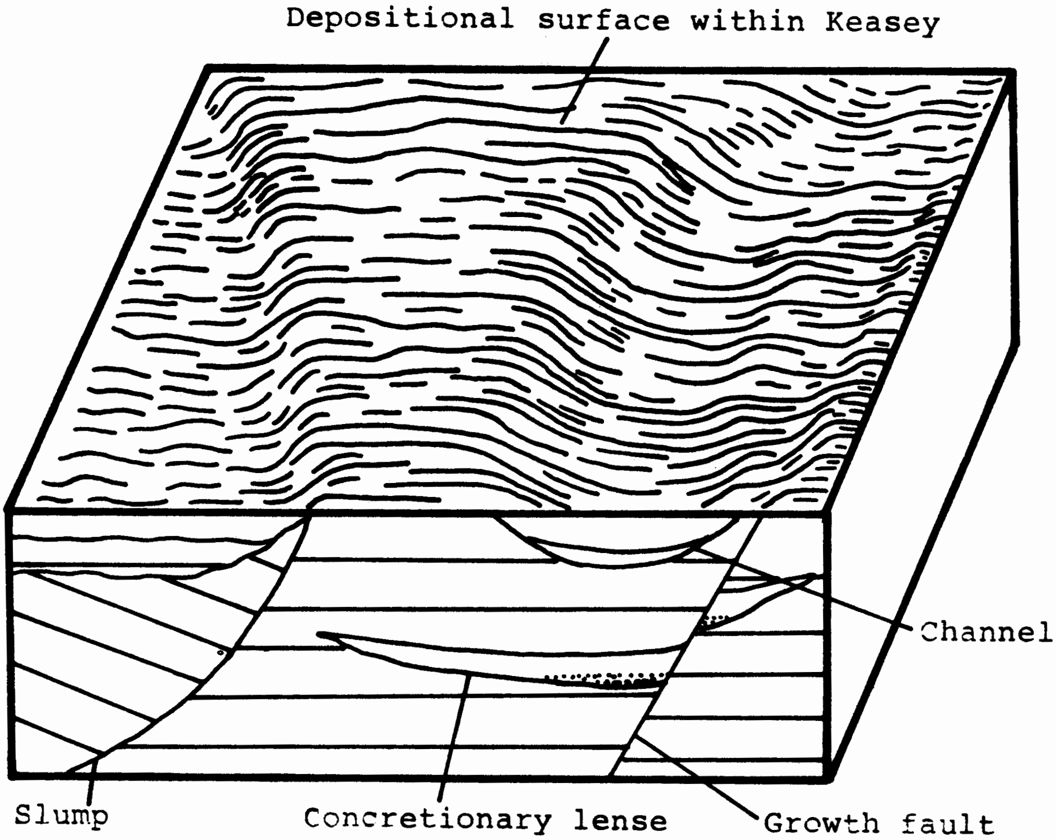


Figure 37. Hypothetical sketch diagram depicting some of the features of the Keasey basin.

fairly complex.

The lutokinesis of the Keasey mudstone, and its low density (compared to the underlying Cowlitz mudstone and overlying Pittsburg Bluff Formation) may not give true clues of the tectonic activity that has acted upon the Tertiary rocks. Post-Keasey rocks however, provide better structural information. The beginning of deltaic sedimentation of the Pittsburg Bluff Formation marks the renewed uplift in the northwestern Oregon Coast Range. The uplift took place along the northeast-trending axis of the Tillamook arch. This post-Keasey uplift produced a structural high on the Oligocene shelf. This structural high appears to have altered existing geometry of the Nehalem River basin, and probably controlled the deposition of the Pittsburg Bluff and younger formations.

Renewed mild uplift occurred, probably during the deposition of the Scappoose Formation. The Columbia River synclinal trough and the embayment began developing, and it may have funneled the marine sediments towards the open sea to the west. From the east, a probable ancestral drainage transported continental as well as volcanic detritus.

The Columbia River embayment was well established by the middle Miocene episode of uplifting, prior to the extrusion of the Columbia River basalt. While the Scappoose Formation was completely removed, the Pittsburg

Bluff Formation was partly eroded away from the nose and crest of the upwarp. To the south, along the axis of the uplift, subaerial erosion of the exposed rocks may have been more pronounced. Therefore, marine as well as non-marine deposition took place in the embayment. The flows of the Columbia River Basalt Group occupied the existing topographic lows in the embayment.

Generally low dips of the strata, and high angle faults not only provide the basic structural data, but act as a constraint in developing a tectonic model for the area. The passive role played by the strata, especially those of post-Eocene age probably preclude uplift involving extensive compression and thrusting. The pi and beta diagram of the Pittsburg Bluff Formation may suggest that the uplift involved northeast-trending, longitudinal, discrete shears along which net vertical displacement occurred. Secondary, transverse shears may have also taken part in the uplift.

Northwest-trending Beta-axis of the Scappoose Formation marks the development of the latest phase of tectonic activity. The exposed northwest-trending horsts and grabens in the northeastern part of the area, probably are the result of the synthetic faults. The major fault zone probably lies farther to the northeast, and appears to be paralleling the northwest-trending Keystone Creek, southeast of Clatskanie. The role played by the northwest trending structure is not clearly ascertained. A right-lateral movement is hypothesized. However, flows of the CRBG are depositionally confined to the structural depressions developed prior to and/or during middle Miocene. No large scale, post-middle Miocene strike-slip offset is apparent from the outcrop pattern of the CRBG. Locally, the Tillamook arch, which appears to have been responsible for restricting the deposition of the Pittsburg Bluff and younger formations, does not indicate a large scale translational offset. Therefore, regional and local surface geology indicators do not indicate large scale right-lateral movement. Therefore, if the exposed northwest-trending horsts and grabens are any clue, then the northwest-trending structures imply a complex form of block faulting which may have associated, minor lateral-slip component. The northwest-trending structure is regional structural grain, and it may have resulted from a complex interaction between the North American and the Pacific plates from their relative spreading rates and direction.

It does not appear that the observed structural pattern can be explained just by the two above mentioned tectonic episodes. The Oregon Coast Range has taken part in clockwise rotation, and paleomagnetic evidence indicates greater rotation during the Eocene than in post-Oligocene time (Magill and Cox, 1980). This indirect evidence, together with the underthrusting of the Pacific plate at the present day continental shelf (Snavely and others, 1980), suggests that the Coast Range has been tectonically active since the Eocene. Therefore, it is likely that this earlier episode of tectonism may have molded the development of the Nehalem River basin, and may have controlled the grain of later structural development.

Post-Keasey uplift along the axis of the Tillamook arch may have played an important role in hydrocarbon migration.

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APPENDIX A

SAMPLE LOCATIONS

The sample numbers indicate section number, township and range. For example, 25-6-5 indicates section 25, township 6 north, and range 5 west.

Sample Number	Comments
6-5-4 B,C,D,E	Southcentral part of section 6, abandoned pit; Columbia River basalt.
3-6-5 B,C,D	NWNE section 3, logging road cut; Columbia River basalt.
COWLITZ FORMATION	
22-4-5	NENWNW section 22; friable, arkosic fine-grained sandstone; collected by R. O. Van Atta.
6-3-5	NW section 6; brown, micaceous mudstone; collected by M. Jackson.
6-3-5 A	Same location as above, 200 mesh fraction.
32-3-5	NW section 32; brown, micaceous mudstone; collected by M. Jackson.
32-3-5 A	Same location as above, 200 mesh fraction.
KEASEY FORMATION	
25-6-5	NE section 25, location of American Quasar's LF 25-32 well; gray, tuffaceous mudstone.
25-6-5 A	Same location as above, 200 mesh fraction.
20-6-4	NW section 20, location of American Quasar's INV MGMT 20-21; gray, tuffaceous mudstone.
20-6-4 A	Same location as above, 200 mesh fraction.
2-5-5	NWSE section 2, logging road cut; gray, moderately weathered mudstone.
23-6-5	East-center of section 23, prominant bluff south of Mist along the Nehalem River; buff colored, moderately weathered laminated mudstone.
23-6-5 A	Same location as above, 200 mesh fraction.
PITTSBURG BLUFF FORMATION	
23-5-4	Center of section 23, type locality of the Pittsburg Bluff Formation; olive gray, lithic arkosic sandstone.
23-5-4 A	Same location as above, 200 mesh fraction.
23-5-4 B	Same location as above, approximately one

	meter stratigraphically higher than the last sample; medium grained sandstone, whole rock.
28-6-4	NW section 28, bluff along Oreg. Hwy. 47; gray, lithic arkosic sandstone.
12-6-5	NE section 12, along Oreg. Hwy. 47 north of Mist; bioturbated, carbonaceous fine grained sandstone, near the top of the section.
12-6-5 A	Same sample as above, 200 mesh fraction.
12-6-5 B	South of above location, middle of Pittsburg Bluff section; bioturbated, carbonaceous siltstone.
12-6-5 C	Same sample as last, 200 mesh fraction.
12-6-5 D	South of the above location, lower in the Pittsburg Bluff section; bioturbated, very fine grained sandstone.
11-6-5	SE section 11, logging road cut; carbonaceous, bioturbated, moderately weathered siltstone.
4-5-4	Extreme SW corner of section 4, north fork of Fall Creek; finely laminated, dark gray mudstone.
ASTORIA FORMATION	
12-6-5 E	NE section 12, along Oreg. Hwy. 47, base of the Astoria Fm., near the contact with the Pittsburg Bluff Formation; clayey, pebbly, fine grained sandstone.
12-6-5 F	Same location as above, 200 mesh fraction.
12-6-5 G	Same location as above, about a meter higher than 12-6-5 E; pebbly, clayey, fine grained sandstone.
12-6-5 H	pebbles from 12-6-5 G, ground and sieved through 200 mesh screen.
6-6-4	NW section 6, location shown in fig. 30; cross-bedded, coarse to medium grained, lithic sandstone.
3-6-5	SE section 3, logging road cut; medium grained lithic sandstone.
3-6-5 A	Same sample as above, 200 mesh fraction.
2-6-5	Extreme SW corner of section 2, road cut NW of Miller gas station; micro cross-bedded, pebbly, clayey, fine grained sandstone.
2-6-5 A	Same location as above, 200 mesh fraction.
2-6-5 B	Smaller outcrop about 100 meters SE of above location; micro cross-bedded, clayey, pebbly, fine grained sandstone.
25-6-5 B	Same location as 25-6-5; pebbly, clayey, very fine grained, slightly micaceous sandstone.
25-6-5 C	Same sample as above, 200 mesh fraction.
25-6-5 D	Same location as above; pebbly fine grained sandstone.
30-6-4	SWSW of 30, road cut; micro cross-bedded, clayey, pebbly, fine grained sandstone.

30-6-4 A	Same sample as last, 200 mesh fraction.
30-6-4 B	About 30 cm higher than last sample, same lithology.
2-5-5 A	Center of 2, logging road cut, in contact with the Keasey Fm.; through cross-bedded, pebbly, clayey sandstone.
2-5-5 B	Same sample as above, 200 mesh fraction.
2-5-5 C	About 200 meters due west of above location; micro cross-bedded, fine grained sandstone.

Samples from the cores and cuttings of the wells are numbered by the depth. Standards W-1 and ARCHO are Columbia River basalt, and O-16 is rhyolite.